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NASA Contractor Report 2970

Expansion of Flight Simulator Capability for Study and Solution of Aircraft Directional Control Problems on Runways

G. W. Kibbee

CONTRACT NAS1-13981
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NASA

NASA Contractor Report 2970

Expansion of Flight Simulator Capability for Study and Solution of Aircraft Directional Control Problems on Runways

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Prepared for
Langley Research Center
under Contract NAS1-13981

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National Aeronautics
and Space Administration

Scientific and Technical
Information Office

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1.0 SUMMARY

This report describes the study performed by Douglas Aircraft Company (DAC) under National Aeronautics and Space Administration (NASA) Contract NAS1-13981 Amendment Modification 2, "Expansion of Flight Simulator Capability for Study and Solution of Aircraft Directional Control Problems on Runways." Principal DAC contributors to this program were: Richard E. Adams, digital antiskid implementation; Paul L. Jernigan, DC-9 airframe implementation; Richard A. Storley, analog antiskid implementation; John A. McGowan, simulator coordination; Gary W. Kibbee, program manager.

The objective of this portion of the contract was to develop a DC-9-10 Runway Directional Control (RDC) Simulator and supply NASA with sufficient documentation to duplicate the simulation at the Langley Research Center. A second objective was to assess the capability of the simulation to be used for training, operational studies, and research.

An existing wide bodied flight simulator was modified to a DC-9-10 configuration. The simulator was structured to use either a digital software or an analog hardware antiskid simulation. The digital software antiskid had been developed by MCAIR under the initial portion of the NASA contract. It furnishes preprogrammed cornering and drag loads. After the total simulation was integrated, pilots evaluated the simulation in four phases: checkout, validation, demonstration, and post demonstration. These evaluations involved landings, rejected takeoffs and various ground maneuvers. A total of 14 pilots evaluated the simulation. The pilots represented DAC, FAA, NASA, an airline, and ALPA. A total of 818 runs were conducted during the evaluations. Pilot quantitative ratings are summarized in Table 1-1. Qualitatively, most pilots evaluated the simulator as realistic and with good potential, especially for pilot training for adverse runway conditions. The pilots all preferred motion over no motion for the simulation. The pilots generally considered the digital antiskid more realistic than the analog antiskid on high friction surfaces because they could feel the motion cue better. However, the digital antiskid did not perform realistically on degraded surfaces. Most pilots

preferred the analog hardware antiskid simulation for low friction runway conditions.

We at DAC appreciate the enthusiastic participation of the simulator evaluation pilots. The program contributions of Ellis White and Tom Yager of NASA, Langley Research Center were instrumental in the success of this program.

TABLE 1-1

RDC PILOT RATING SUMMARY

1: Excellent
10: Major Deficiencies

PHASE \ CATEGORY	CONTROL DURING APPROACH	GROUND DIRECTIONAL CONTROL	WIND	RUNWAY ROUGHNESS	BRAKING DECELERATION	THRUST REVERSE	VISUAL	MOTION
VALIDATION		2.87	2.5	2.13	3.26	3.97	3.01	3.10
DEMONSTRATION	3.50	4.89		2.5	4.91		3.67	
POST DEMONSTRATION	3.77	3.58			3.01		3.72	3.07
PROGRAM AVERAGES	3.64	3.78	2.5	2.32	3.73	3.97	3.49	3.09

2.0 INTRODUCTION

Work accomplished under this contract amendment represents the third step in a NASA program to study aircraft directional control problems on runways. Such problems can be caused by slippery runways, crosswinds, reduced visibility, extended touchdown points, excessive velocity, insufficient directional control, equipment malfunction, and aircraft configuration constraints and limitations.

In the past, work has been concentrated on optimizing aircraft stopping performance, with less emphasis placed on the equally critical directional control. Aircraft performance during takeoff and landing is traditionally explored when the aircraft is in the flight test phase. But by that point, necessary changes are expensive to incorporate. Moreover, only part of the directional control characteristics envelope can be safely examined in flight test.

To study aircraft directional control problems on runways, NASA has been sponsoring the development of an effective simulator as a design and evaluation tool for safely exploring aircraft directional control and braking performance under adverse runway conditions. Once this simulation capability is developed, the potential applications include:

- Aircraft configuration trade studies in the aircraft design phase.
- Establishing safe operational limits for existing aircraft.
- Optimizing pilot techniques on adverse runways.
- Defining regulatory requirements for aircraft and runway design.
- Training pilots for adverse runway conditions.
- Accident investigations.
- Incorporation into 100% simulator training simulations.

The first phase of the program was to define and demonstrate the hardware and computer software necessary to expand current flight simulator

capability for study and solution of aircraft directional control problems on runways. The USAF-MCAIR F-4 aircraft was selected for this study.

The MCAIR five-degree-of-freedom motion-base simulator (MBS) was used in combination with a six-degree-of-freedom aircraft mathematical model to demonstrate the simulation adequacy on dry, wet, flooded, and icy uncrowned runways with steady state and gusty crosswinds.

Three F-4 experienced pilots representing NASA, FAA, and USAF participated in the 130 approach-touchdown-rollout demonstration and verified the simulation feasibility. The report for this contract effort is contained in Reference 1.

The second phase of the program was to extend the aircraft ground handling simulation technology to include simulation of a jet transport and to refine the simulator technology to include runway crown, roughness and patchy friction effects. Another objective was to initiate the development of a skid control braking system simulator to duplicate combined braked and yawed tire rolling conditions. The development of the skid control braking system simulator was initiated by the Hydro-Aire Division of Crane Company. The DAC DC-9 aircraft was selected for this effort. The MCAIR F-4 aircraft (USAF Model E) was also included in this study.

The MCAIR five-degree-of-freedom MBS and the MCAIR fixed base simulator (MACS III) were used in combination with a six-degree-of-freedom aircraft mathematical model to demonstrate simulator adequacy under diverse runway friction conditions and runway profiles, and with steady-state and gusty crosswinds. Four experienced pilots representing NASA, FAA, DAC, and USAF participated in 320 landing, takeoff, and rejected takeoff demonstration runs in March 1976. They evaluated both the DC-9 and F-4 simulation adequacy. This contract effort is documented in Reference 2.

The present study was conducted to extend the earlier work to a six-degree-of-freedom motion base transport cockpit and to include an actual real time antiskid simulator. A DC-9-10 simulation was developed such that this

analog antiskid or a simplified digital antiskid simulation could be used. This simulation was flown from a transport cockpit mounted on a six-degree-of-freedom moving base. The pilots who flew the simulation evaluated both antiskid simulations with and without motion.

NASA will use the technology developed for this program to construct a similar simulation at the Langley Research Center. Volume II of this final report contains the technical description, mathematical models, data tables, programming considerations, and equations used for the DC-9-10 aircraft simulation at DAC.

3.0 ABBREVIATIONS AND SYMBOLS

ALPA	Air Line Pilot Association
A/S	Antiskid
DAC	Douglas Aircraft Company
EPR	Engine Pressure Ratio
FAA	Federal Aviation Administration
F_N	Engine Thrust Level
MBS	Motion Base Simulator
MCAIR	McDonnell Aircraft Company
NASA	National Aeronautics and Space Administration
PMV	Pilot Metering Valve
RDC	Runway Directional Control
RTO	Rejected Takeoff
USAF	United States Air Force
V_{MCG}	Minimum Control Speed Ground

4.0 SIMULATOR DESCRIPTION

4.1 PROGRAM LAYOUT

The simulator developed for this program was mechanized as shown in Figure 4-1. A jet transport cockpit with visual displays and flight instruments was mounted on a six-degree-of-freedom motion base. Cockpit control deflections provided inputs to the computer which generated appropriate drive signals to the motion base, visual scene drive, and instrument drive.

One of the purposes of this program was to compare performance with the antiskid mechanization developed in References 1 and 2 with performance obtained with a simulator which used actual aircraft antiskid hardware. For this reason the simulator was configured so either an analog hardware or a digital software simulation of the antiskid could be used. Details of how these antiskid simulators are incorporated into the system are shown in Figure 4-2.

When the simulator was operating in the digital antiskid mode the digital antiskid was used to determine drag and cornering force for each main gear and nose gear. When in the analog antiskid mode, the analog antiskid was used to determine drag and cornering load for each main gear while the drag and cornering forces for the nose gear were calculated with the digital antiskid.

Details of the airframe, digital antiskid, analog antiskid, and cockpit are given in Appendices A, B, C, and D respectively of Volume II.

4.2 COCKPIT

The cockpit used for this simulation was originally a DC-10 cockpit. Figure 4-3 shows the cockpit interior. Seats for pilot, first officer, and observer were provided. Visual displays were provided for the pilot and first officer. Instruments showing airspeed, attitude, glide slope deviation, heading, localizer deviation, absolute altitude, radar altitude,

and vertical speed were active for the pilot and first officer. The pilot's instruments were configured as in a DC-9 and the first officer's were configured as in a DC-10. The pilot's instruments are shown in Figure 4-4. The column, wheel, and rudder pedals for pilot and first officer furnished primary flight control inputs to the computer. Pitch trim was activated by a thumb switch on the left horn of the pilot's wheel. Nose wheel steer angle was locked in the neutral position (aligned with the aircraft body axis) until the nose gear had deflected 5.08 centimeters (2 inches). For greater deflections nose wheel steer angle was controlled by rudder pedal deflection. Left and right main gear brake application was controlled by toe brake deflections. The hand tiller nose wheel steer control handle was not active.

The flap handle controlled the flap setting which was either 15° (RTO's) or 50° (landings) for this program. The spoiler handle controlled manual spoiler position. The handle did not move for automatic spoiler extension during landing.

Two thrust levers and engine pressure ratio (EPR) gages were active for the program. Thrust reverse was controlled by the piggy-back levers. A thrust interlock was mechanized that prohibited appreciable reverse thrust application until the reverse buckets were deployed. It functioned as follows: When the throttles were returned to the idle position, the piggy-back levers could be moved on[illegible] to a stop. This lever movement would cause an amber light to be illuminated which indicated "buckets in motion." After 1 to 2 seconds a green light would light and the piggy-back stop would be removed at which time full reverse could be applied.

4.3 MOTION BASE/MOTION DRIVE

The cockpit is mounted on a Douglas designed and fabricated six-axis motion simulation system as shown in Figure 4-5. This system employs proprietary techniques to provide realistic motion cues. Six axis motion is provided by six hydraulic jacks arranged in the configuration developed by the Franklin Institute. The motion base specifications are summarized below.

Axis	Excursion	Velocity	Acceleration
Heave	± 107 cm (± 42 in)	± 99 cm/sec (± 39 in/sec)	± 1.65g
Sway	± 171 cm (± 67.5 in)	± 170 cm/sec (± 67 in/sec)	± 1.43g
Surge	± 165 cm (± 65 in)	± 180 cm/sec (± 71 in/sec)	± 1.50g
Roll	± 30.7 deg	± 35.6 deg/sec	± 7.8 rad/sec^2
Pitch	± 33.3 deg	± 33.6 deg/sec	± 7.8 rad/sec^2
Yaw	± 38.7 deg	± 36.3 deg/sec	± 7.9 rad/sec^2

These figures are predicated on a total moving mass of 9072 kilograms (20,000 pounds). The figures for pitch and yaw refer to the platform axis. With the separation between aircraft center of gravity and the pilot's position, the pitch and yaw motions appear primarily as heave and sway.

The motion system is controlled by a minicomputer satellite which implements the geometric transformations, washout algorithms, as given in Reference 3, and failsafe features. The minicomputer is tied to the Sigma 5 computer via a digital data link. The minicomputer exercises closed-loop control over the motion system via digital/analog converters to the servo valves and receives feedback data, via analog/digital converters, from linear variable differential transformers.

4.4 ANTISKID BRAKE SYSTEM

4.4.1 Digital Antiskid System

The digital antiskid model used at DAC was developed in Phase I and Phase II of this program to furnish preprogrammed tire drag and side forces during ground operation. The model is documented in Reference 4. For the main gears, the simulation selects a drag and cornering friction coefficient for the current aircraft velocity, tire skid angle, and runway condition. Three conditions are considered: no braking, partial braking, and braking sufficient to cause the antiskid to cycle. Unlike a true antiskid, the friction coefficients are independent of past performance. The model is also used to determine the nose gear tire cornering force.

The tire force data base for the main gears used with the model was obtained from averaged test data given in Reference 5. Antiskid cycling periods, proportion of time on, and onset of antiskid cycling were obtained from Reference 6. The nose gear data was ultimately adjusted to reflect results of Reference 7.

4.4.2 Analog Antiskid System

The analog antiskid system was implemented as shown in Figure 4-6. The simulation consists of an analog computer and actual aircraft hardware. The analog computer solves the equations of strut and tire motion. An analog computer was selected to solve these equations because of the high frequencies involved and the simplicity of the hardware interface.

This simulation computes a drag and cornering force for the current exact tire slip speed, aircraft velocity, tire skid angle, and runway condition. Since the friction coefficient is a function of tire speed, the current performance is influenced by previous conditions because of tire inertia.

In the brake system hardware, hydraulic pressure is applied to either strut antiskid valve by the pilot metering valves (PMV). The antiskid valves modulate this pressure to the brake in response to electrical signals originating in the antiskid control box. Brake pressure is measured and converted to brake torque in the analog computer circuits. The antiskid control valve drive signal is computed in the controller and is related to rate of wheel speed change and time.

Photographs of the antiskid hardware are shown in Figure 4-7. This equipment was loaned to DAC for the simulation program by Hydro-Aire Division, Crane Company.

4.5 VISUAL SYSTEM

The Redifon visual simulator consists of a model, a servo-driven television camera and the associated control electronics and lighting. Photographs

of the visual system are shown in Figures 4-8 and 4-9. The model, which consists of the airport, runway, and surrounding terrain, is a three-dimensional model 13 meters (42.5 feet) long by 4.6 meters (15 feet) wide, with a scale of 750 to 1. A 3048 meter (10,000 foot) runway is located in the longitudinal center of the model. The runway is complete with approach lights, strobes, marker and threshold bars, touchdown zone, taxiway, edge, and centerline lights. The model is illuminated by a bank of fluorescent lights.

A television camera is mounted on a gantry. The gantry travels on tracks parallel to the model to provide longitudinal motion. The camera carriage itself is driven in two directions to provide lateral motion and changes in altitude. Servo-driven mirrors and prisms in the optics of the camera provide roll, pitch and yaw.

The Sigma 5 computer which solves the equations of motion is linked to a control computer which converts aircraft c.g. coordinates to pilot's eye coordinates and controls camera motion. The camera then "flies" the approach as directed from the cockpit.

The video signal is sent to television monitors which are viewed by the pilots through collimating lens mounted approximately in the plane of the windscreen. The monitors are masked to give the DC-9 field of vision. Specifications for the visual system are given in the following paragraph.

The maximum approach distance is 3.62 kilometers (2.25 miles). The eye altitude range of the airport model is 221 meters (725 feet) (maximum) to 3.4 meters (11 feet) (minimum). Maximum longitudinal and lateral velocities are 225 kts and maximum sink rate is 610 meters/minute (2000 feet per minute). The maximum pitch is ± 24-1/2 degrees; heading and roll are unlimited. Maximum angular velocities are 0.75 rad/second (heading), 0.5 rad/second (roll), and 1.5 rad/second (pitch). Maximum angular accelerations are 0.5 rad/second^2 (heading), 1.0 rad/second^2 (roll), and 3.5 rad/second^2 (pitch). Angular field of view is 48 degrees horizontal (± 24 degrees) and 36 degrees vertical (+16 degrees; -20 degrees).

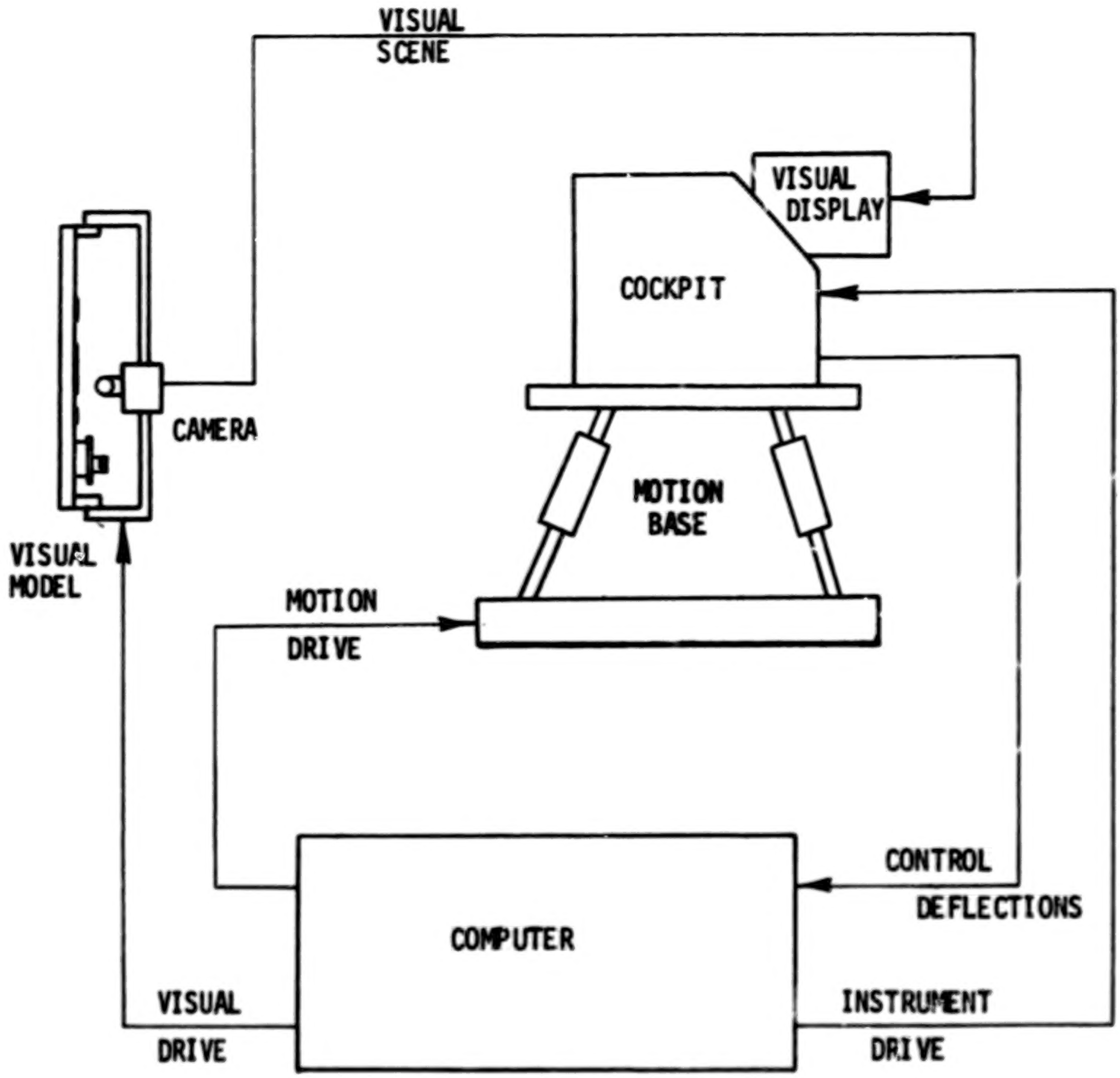


FIGURE 4-1 SIMULATOR BLOCK DIAGRAM

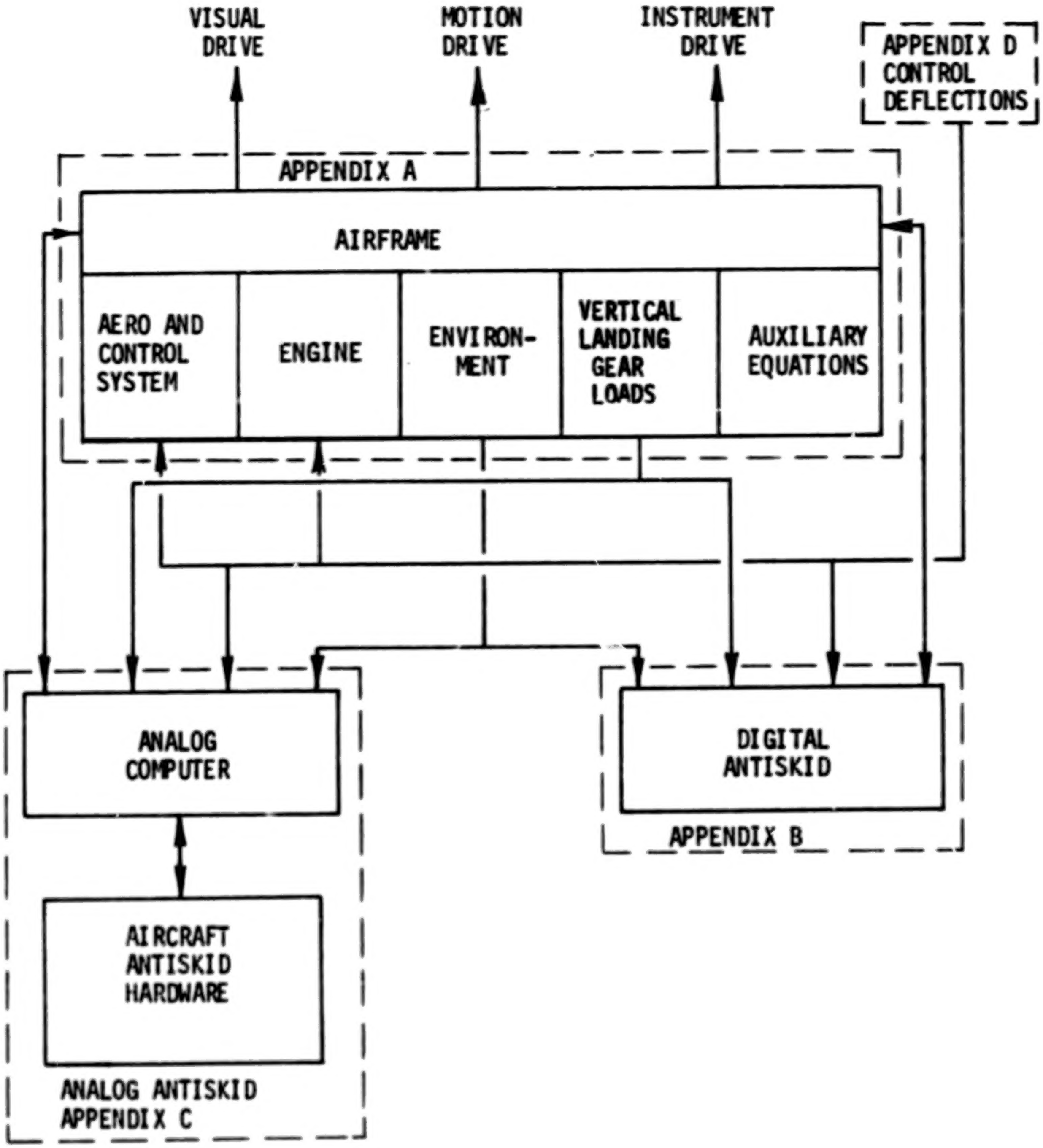


FIGURE 4-2 SIMULATOR DETAILS

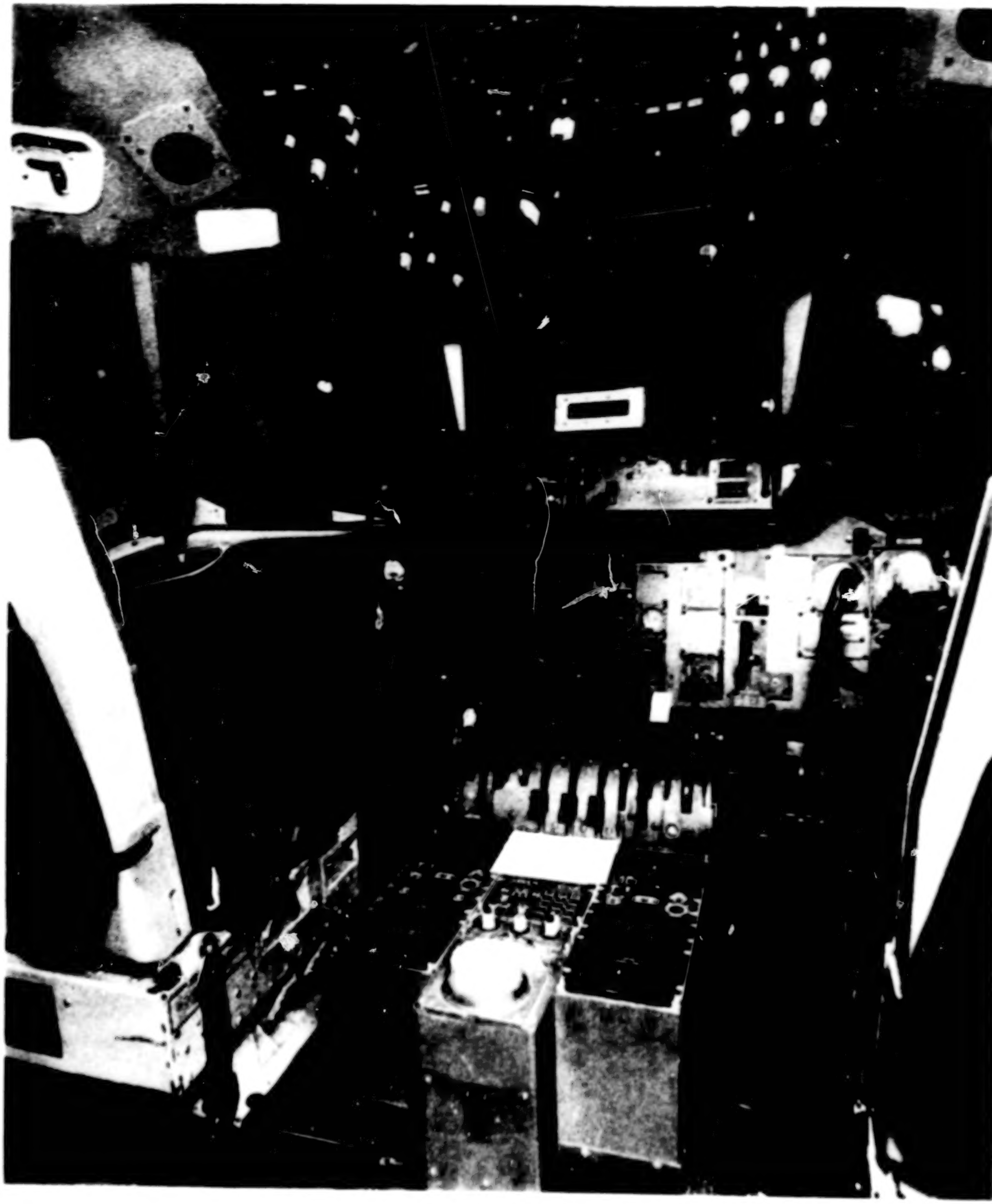


FIGURE 4-3 COCKPIT INTERIOR

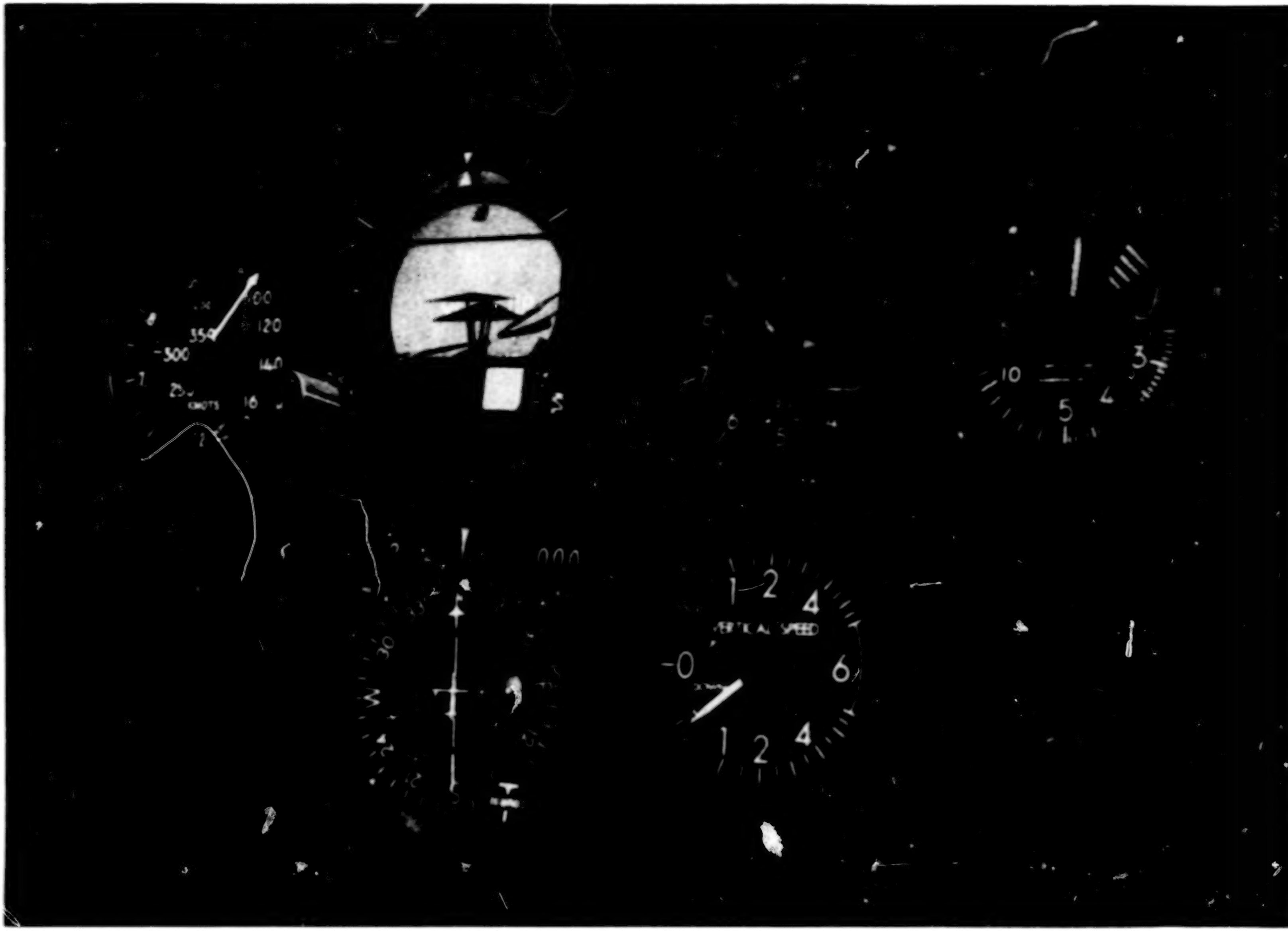


FIGURE 4-4 PILOT'S INSTRUMENTS

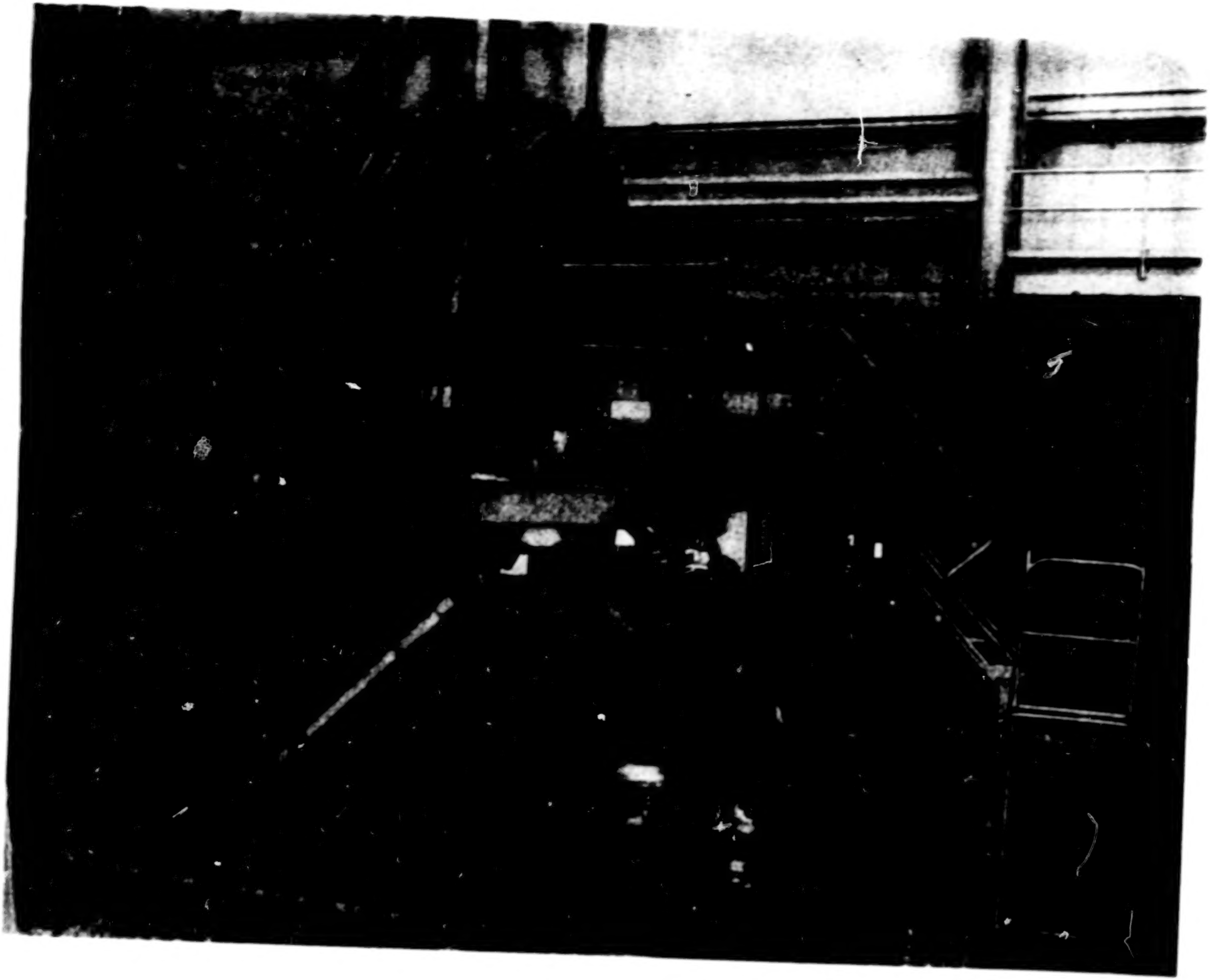


FIGURE 4-5 MOTION BASE

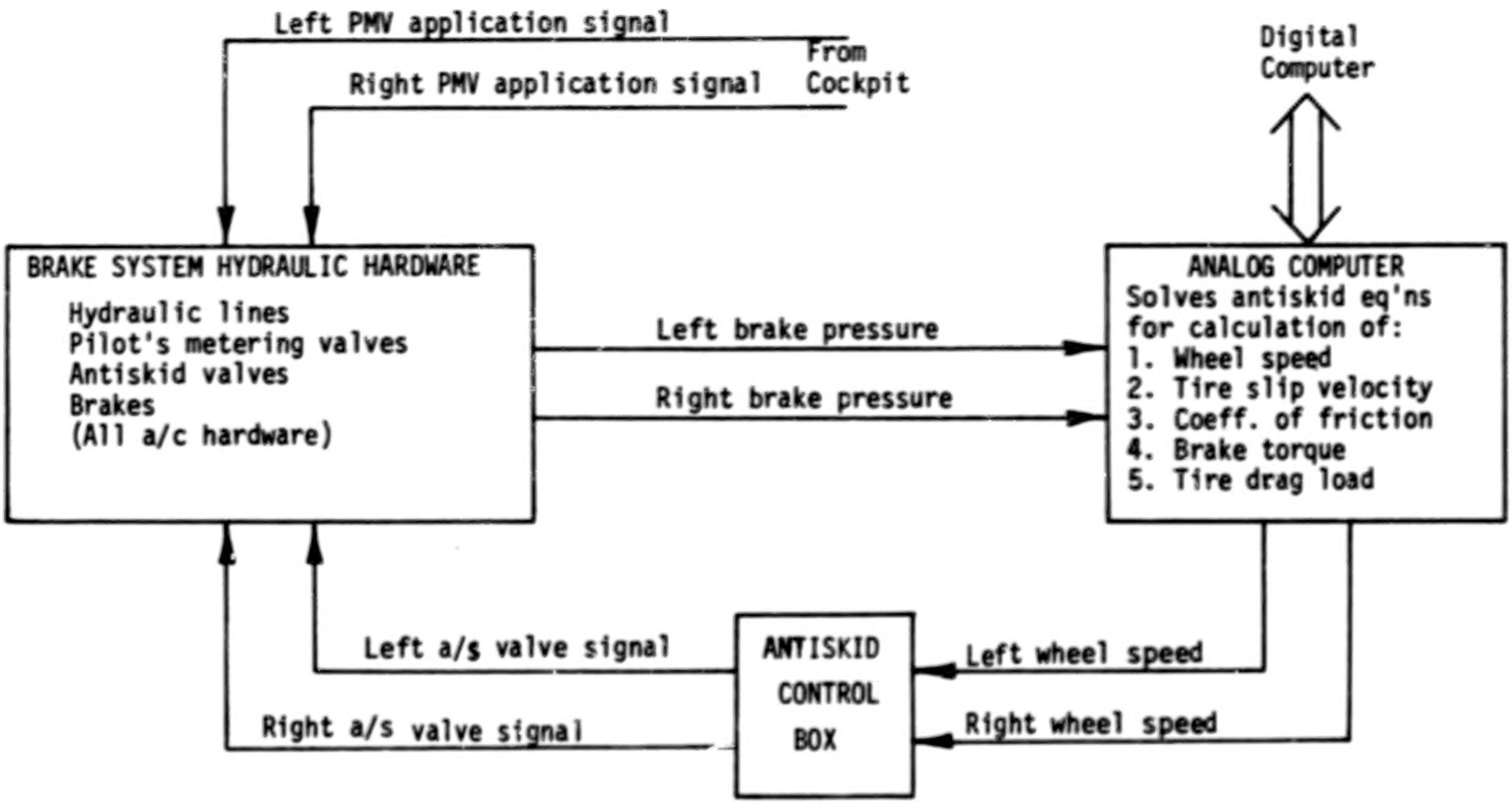
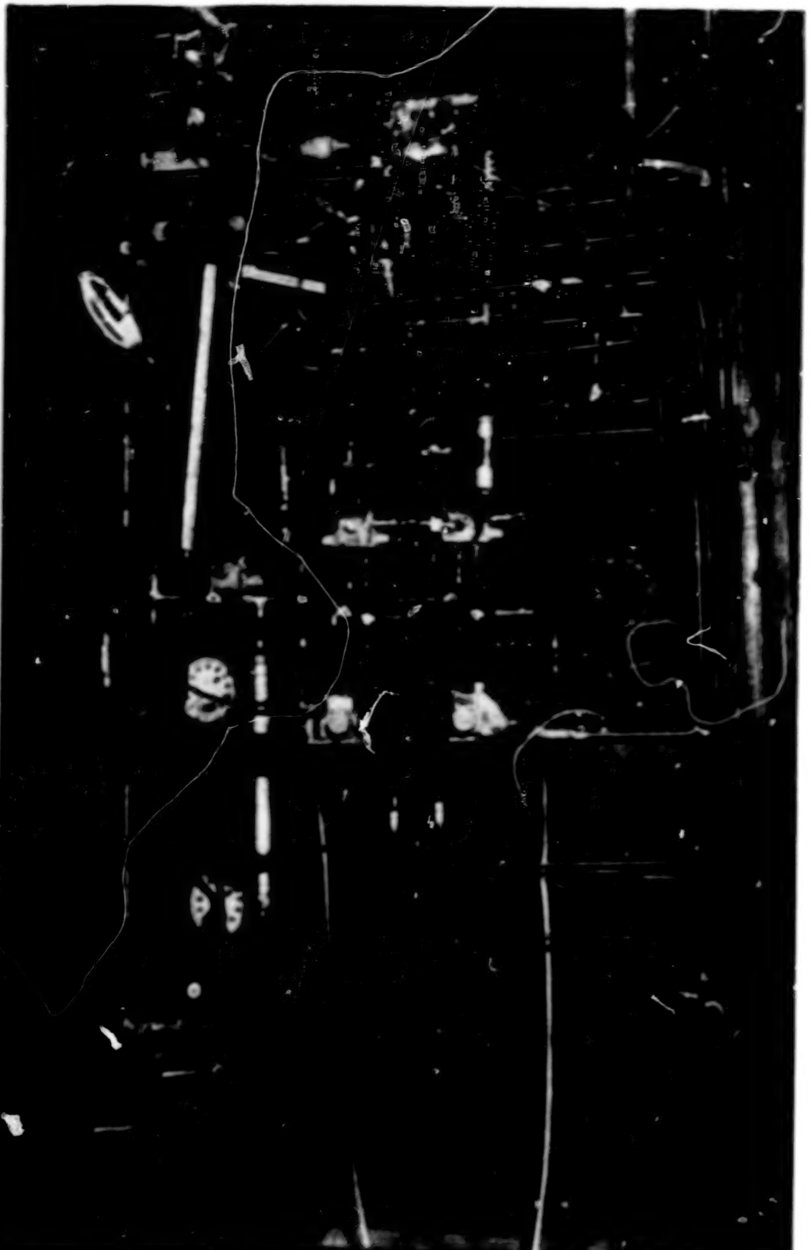


FIGURE 4-6 ANALOG ANTISKID BLOCK DIAGRAM



(b) BRAKES

(a) BRAKE HYDRAULIC SYSTEM

FIGURE 4-7 ANALOG ANTISKID HARDWARE ARRANGEMENT

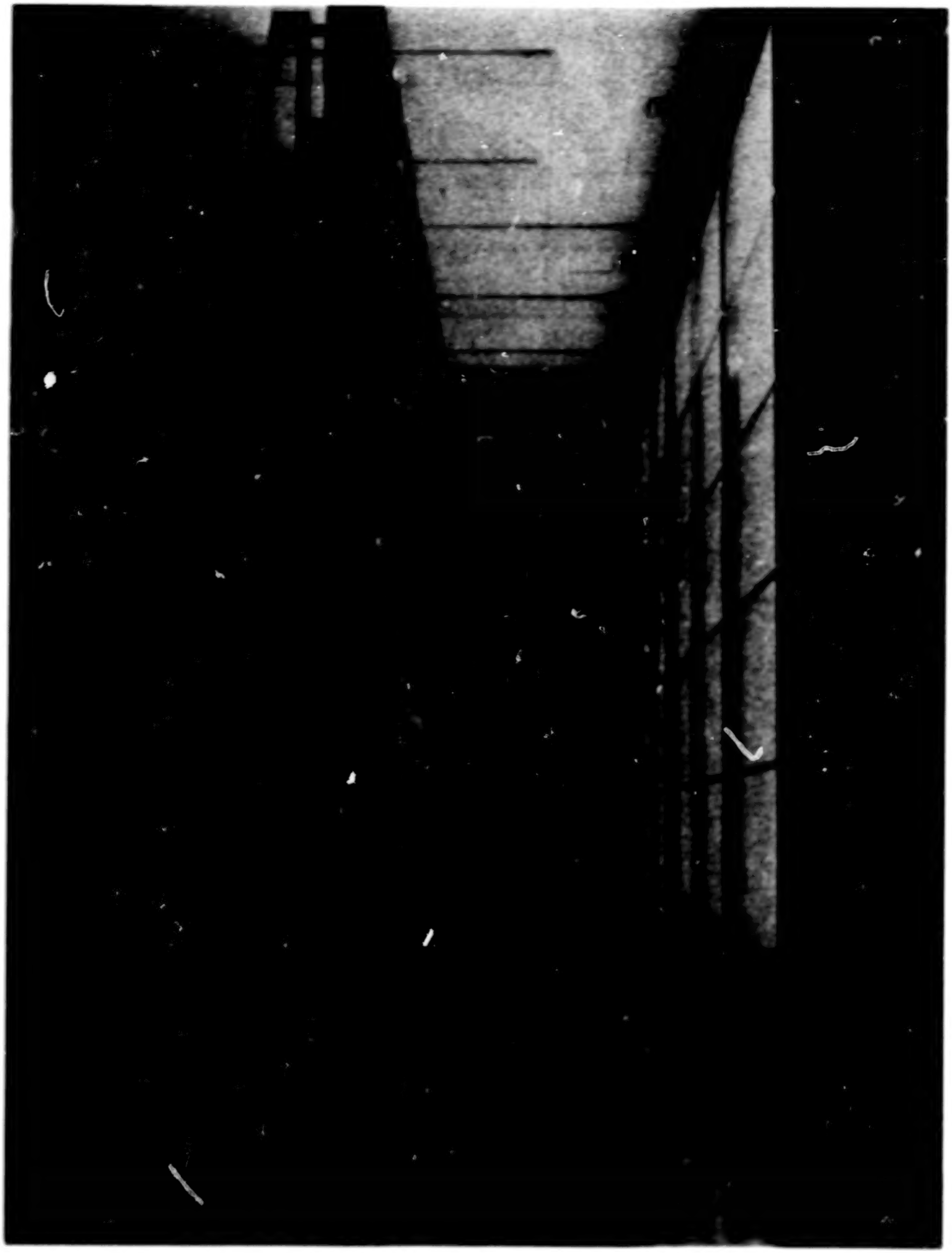


FIGURE 4-8 OVERALL VIEW OF VISUAL SYSTEM

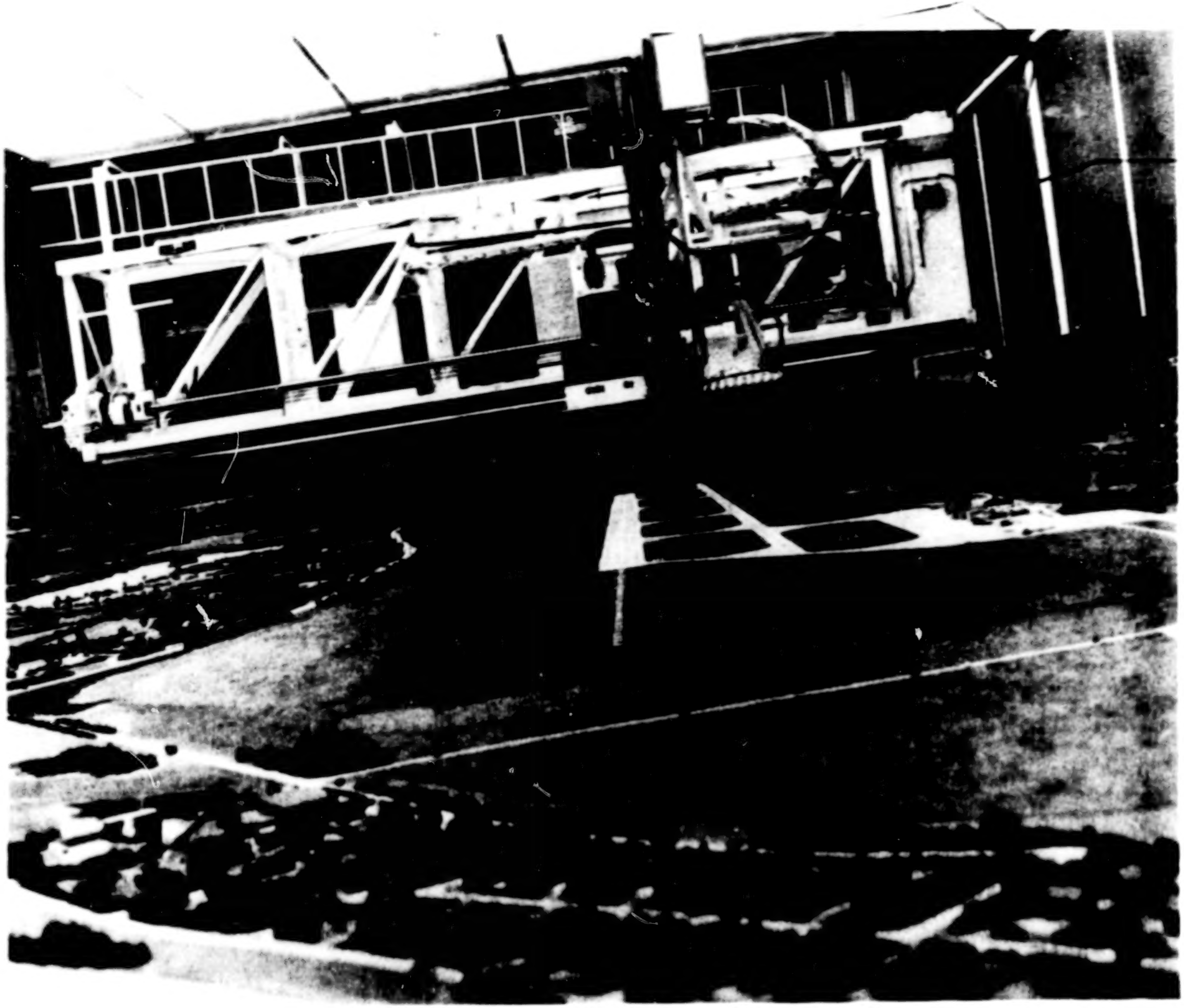


FIGURE 4-9 VIEW OF MODEL FROM APPROACH DIRECTION

5.0 PROGRAM DESCRIPTION

5.1 PILOTS

Fourteen pilots took part in the program. George Jansen, DAC Chief Pilot - Engineering was only involved with the checkout phase and did not give ratings. Each pilot for the validation, demonstration, and post demonstration phases, was given the resume form shown in Figure 5-1, a NASA questionnaire concerning the motion and visual systems, and the opinion form shown in Figure 5-2. A summary of the pilots' background compiled from the resumes is given in Table 5-1.

Each pilot flew several 1 to 3 hour sessions. An observer and the test director rode the simulator with the pilot to prompt and record pilot comments. Each flight followed a flight card which had been prepared before the flight. Additional tests were added when the pilot was not satisfied with a run or wanted to use a different procedure. The tests and configurations called for on the flight cards are tabulated in Table 5-2.

Table 5-3 summarizes which phase each pilot flew, specific flight cards flown, and the number of runs made.

5.2 PROCEDURES

Unless specified differently on the flight cards the runs were made as follows:

Landing - The pilot was given the trimmed aircraft at 107 meter (350 foot) altitude and 133 knot ICAS. Flaps were at 50°, spoilers were stowed, and throttle set. He flew the approach with visual and instrument aids. At touchdown spoilers were deployed automatically and the pilot applied maximum brakes until the aircraft stopped. If thrust reversers were called for, normal procedures were followed with thrust reduction at 60 knots.

Rejected Takeoff (RTO) - The pilot was given the aircraft at rest at the end of the runway. Flaps were set at 15°, spoilers were stowed, and throttles were at idle. Brakes were applied and throttles were set to give 1.95 EPR on both engines. The brakes were released and the aircraft accelerated to 126 knots at which time the pilot closed the throttle, deployed the spoilers, and applied maximum braking until the aircraft stopped. If thrust reversers were called for normal procedures were used.

Turns - The pilot would transition from the active runway to a high speed turnoff.

Minimum Control Speed Ground (V_{MCG}) - For this maneuver the nose gear steering was disconnected. The runs were started with the aircraft at rest with flaps at 15° and spoilers stowed. With brakes applied, the thrust was set at a value that would give either 40.9 or 49.8 kilonewtons (9 200 or 11 200 pounds) of engine thrust at the V_{MCG} speed. Brakes were released and the aircraft was accelerated to the target speed. At this speed one throttle was closed which caused the aircraft to yaw. As soon as the pilot perceived the yaw, he would arrest it with a hardover rudder. The maximum lateral deviation measured from the initial deviation was then recorded to correspond to the actual aircraft speed when the throttle was closed. For the DC-9-10 airplane, V_{MCG} is the speed at which the lateral deviation is 4.6 meters (15 feet).

5.3 SYSTEM CHECKOUT

The system checkout phase was a series of development runs conducted to find and correct operational problems with the simulation and to adjust portions of the simulation to meet pilots' qualitative criteria. This phase consisted of six days of pilot evaluation and numerous other development sessions. Subsystem checkouts of the aero software and analog antiskid were conducted independently as discussed in Appendices A and C respectively.

During the system checkout phase informal flight cards were developed that would emphasize the particular portion under study. The following changes were made to the simulation during this phase:

Nose gear steering - The simulation was started with the same nose gear sensitivity as documented in Reference 4. The pilots felt that this was too sensitive. The value was then reduced to a value in agreement with Reference 7. The pilots still felt this was too sensitive so the sensitivity was reduced another 10%. The sensitivity remained at this value for the remainder of the checkout and validation. Also, the rate limit in the nose gear system was replaced by a 1 second lag.

Digital antiskid - The logic and the brake torque gain was changed to obtain antiskid braking activity when it should occur. Also, the cycling frequency and proportion of the cycle that the force was on was changed from the values of Reference 4 to values of Reference 6 to make the motion felt in the cockpit more realistic.

Runway roughness - The runway profile used was a 732 meter (2400 foot) length of Travis AFB repeated to obtain a 3049 meter (10 000 foot) runway. The same profile had been used in Reference 2. The pilots did not sense enough motion with the basic profile so the input magnitude was increased. The pilots felt that the acceleration produced with a factor of two was satisfactory. This had also occurred during the runs of Reference 2.

Since the basic runway profile had produced similar results in two independent simulations, an elevation power spectral density analysis was performed with the factored data to determine the relative roughness of the runway compared to other surfaces. The results are shown in Figure 5-3 compared to data from References 8 and 9. At the higher frequencies, the factored data was between "new construction" and "paved runway". The unfactored data would result in an elevation power spectral density with a magnitude one fourth the factored values or smoother than "new construction". Thus the basic runway is very smooth.

Analog antiskid - The analog antiskid did not produce enough motion in the cockpit so a change was made to make the operation rougher and hence more inefficient. The change involved the u-slip curve and is reflected in the data presented in Appendix C.

5.4 SYSTEM VALIDATION

The system validation phase was a series of tests to determine the degree of correlation between the simulator and the aircraft. The areas checked are summarized in Table 5-4 together with the flight cards that were used. The pilots evaluated the qualitative runs by assigning a Cooper rating to the runs. During these tests simulator parameters were recorded on four or five 8 channel oscillograph recorders.

As a result of the validation runs the nose gear steering sensitivity was increased to the value that agrees with Reference 7. This change was made because both pilots thought the steering was not sensitive enough. Also the one second time constant was reduced to one half second.

5.5 DEMONSTRATION

The demonstration phase was a series of tests that were designed to determine the adequacy of the digital and analog antiskid simulations and to determine the need for cockpit motion. After the pilots had flown the familiarization card H; they flew the digital antiskid landing card I, the analog antiskid landing card J, the dry, wet, and flooded RTO card L, and the dry and patchy RTO card M. The pilots evaluated the realism of these runs with the aircraft by assigning a Cooper rating. Only a few no motion runs were included since pilots had expressed a clear preference for motion

An additional card N was added to take the place of the original no motion runs that had been planned. This card was designed: (a) to gather information about how antiskid performance and cornering capability were influenced by runway roughness, (b) to develop pilot technique for flooded

runways, and (c) to determine the influence of wet and flooded runways on turning.

5.6 POST DEMONSTRATION

The post demonstration phase was added to the original program to permit additional pilots selected by NASA and FAA to evaluate the simulation. After the first three pilots had flown the familiarization card H, they flew card K which included both digital and analog antiskid simulations with and without motion. A different familiarization card O and post demonstration card P was developed and used by the remaining six pilots.

RDC SIMULATOR PILOT RESUME

NAME: ______________________ EMPLOYER: ______________________

TEST PILOT ☐ OPERATIONAL PILOT ☐ CHECK PILOT ☐

TRANSPORT TIME ______ HR. DC-9 TIME ______ HR. SIMULATOR TIME ____ HR.

WHEN WAS THE LAST TIME YOU HAVE FLOWN A DC-9 AIRCRAFT ______________

APPROXIMATE NUMBER WET/FLOODED LANDINGS: __________

IN TRANSPORT AIRCRAFT: __________

IN DC-9 AIRCRAFT: __________

IN OTHER AIRCRAFT: __________

HAVE YOU EVER EXPERIENCED HYDROPLANNING? __________

IF YES, PLEASE GIVE APPROXIMATE NUMBER AND AIRCRAFT TYPE

____

____

____

____

HAVE YOU EVER HAD ANY PROBLEMS WITH AIRCRAFT DIRECTIONAL CONTROL OR STOPPING PERFORMANCE ON THE RUNWAY:

____

IF YES, EXPLAIN: ____

____

____

____

FIGURE 5-1 PILOT RESUME FORM

HOW WOULD YOU RATE THE RDC SIMULATION FOR USE IN THE FOLLOWING APPLICATIONS?

APPLICATION	ACCEPTABLE AS IS	NEEDS MINOR REVISION	NEEDS MAJOR REVISION
OPTIMIZING PILOT TECHNIQUES ON ADVERSE RUNWAYS			
TRAINING PILOTS FOR ADVERSE RUNWAY CONDITIONS			
INCORPORATION INTO 100% SIMULATOR TRAINING SIMULATIONS			
ACCIDENT INVESTIGATIONS			
CONFIGURATION TRADE STUDIES IN THE AIRCRAFT DESIGN PHASE			
ESTABLISHING SAFE OPERATIONAL LIMITS FOR EXISTING AIRCRAFT			
DEFINING REGULATORY REQUIREMENTS FOR AIRCRAFT AND RUNWAY DESIGN			
OTHER			
COMMENTS:			

NAME ______________________________

FIGURE 5-2 PILOT OPINION FORM

TABLE 5-1

RDC SIMULATOR PILOT RESUME SUMMARY

PILOT DESIGNATION	NAME	REPRESENTING	PILOT TYPE			TRANSPORT TIME	DC-9 TIME	SIMULATOR TIME	LAST DC-9 FLIGHT	WET/FLOODED LANDINGS			EXPERIENCED HYDROPLANNING?
			TEST	OPERATIONAL	CHECK					TOTAL	TRANSPORT	DC-9	
A	Nick Knickerbocker	DAC	X			800	600	500					
B	George Lyddane	FAA	X			2500	100	250					
C	Dave Wiebracht	DAC		X	X	8600	2176	312	7/31/77	150	130	30	Yes
D	Joe Tymczyszyn	FAA	X			3400	50	500		10	3	0	Yes
E	Perry Deal	NASA	X			2500	0	2000	-	125	25	0	Yes
F	Ernie Southerland	FAA	X			8000	900			90	90	90	Yes
G	Don Armstrong	FAA	X			500	40	100	1972	0	0	0	No
H	Ron Weinert	ALPA		X	X	8000	300	100	7/25/77	1000-2000	500-1000	5 to 10	Yes
I	John Altree	ALPA		X	X	12000	3000	50	Current	2000	2000	500	Yes
J	Sal Nucci	FAA		X		6000	0	200	-	50	50	0	No
K	Alan Passingham	Air Canada		X	X	12000	2500	500	8/1/77	Many wet some flooded			Yes
L	Ken Erdman	FAA	X			2000	200	2	8/76	6	0	0	Yes
M	Jim Bugbee	FAA	X			5000	100	0	1/77	200	100	4	Yes

TABLE 5-2

FLIGHT CARD TEST CONDITIONS

CARD	RUN NO.	RUN TYPE				PROFILE		RUNWAY CONDITION					WINDS			DECEL			MOTION		A/S		EPR	VEL	CARD OBJECTIVES
		RTO	LDG	VMCG	TURN	SMOOTH	ROUGH	DRY	WET	FLOODED	SYM PATCHY	UNSYM PAT.	CALM	STEADY	GUSTS	NO BRAKES	BRAKES	REVERSERS	ON	OFF	DIGITAL	ANALOG			
A	1		●				●	●					●				●		●		●				VALIDATION FAMILIARIZATION
	2		●				●	●						●			●	●	●		●				
	3		●				●	●						●	●		●	●	●		●				
	4	●					●	●						●	●		●	●	●		●				
B	1			●		●		●					●						●		●		1.64	80	V_{MCG} VALIDATION WITH DIGITAL ANTISKID
	2			●		●		●					●						●		●		1.64	75	
	3			●		●		●					●						●		●		1.64	70	
	4			●		●		●					●						●		●		1.64	65	
	5			●		●		●					●						●		●		1.82	90	
	6			●		●		●					●						●		●		1.82	85	
	7			●		●		●					●						●		●		1.82	80	
	8			●		●		●					●						●		●		1.82	75	
C	1			●		●		●					●						●			●	1.64	80	V_{MCG} VALIDATION WITH ANALOG ANTISKID
	2			●		●		●					●						●			●	1.64	75	
	3			●		●		●					●						●			●	1.64	70	
	4			●		●		●					●						●			●	1.64	65	
	5			●		●		●					●						●			●	1.82	90	
	6			●		●		●					●						●			●	1.82	85	
	7			●		●		●					●						●			●	1.82	80	
	8			●		●		●					●						●			●	1.82	75	
D	1		●			●		●					●				●		●			●			LANDING DISTANCE VALIDATION
	2		●				●	●					●				●		●			●			
	3		●				●		●				●				●		●			●			
	4		●			●			●				●				●		●			●			
	5		●			●		●					●				●		●		●				
	6		●				●	●					●				●		●		●				
	7		●				●		●				●				●		●		●				
	8		●			●			●				●				●		●		●				
E	1		●				●	●					●			●			●		●				QUALITATIVE APPROACH AND LANDING VALIDATION
	2		●				●	●					●				●		●		●				
	3		●				●	●					●				●		●			●			
	4		●				●	●					●					●	●		●				
	5		●				●	●					●				●	●	●		●				
	6		●				●	●						●			●	●	●		●				
	7		●				●	●						●	●		●	●	●		●				
	8		●				●		●				●				●	●	●		●				
	9		●				●				●			●			●		●		●				

TABLE 5-2 (Continued)

FLIGHT CARD TEST CONDITIONS

CARD	RUN NO.	RUN TYPE				PROFILE		RUNWAY CONDITION					WINDS			DECEL			MOTION		A/S		CARD OBJECTIVES
		RTO	LDG	VMCG	TURN	SMOOTH	ROUGH	DRY	WET	FLOODED	SYM PATCHY	UNSYM PAT.	CALM	STEADY	GUSTS	NO BRAKES	BRAKES	REVERSERS	ON	OFF	DIGITAL	ANALOG	
E	10		●				●					●		●			●		●		●		
	11		●				●					●		●			●		●			●	
	12		●				●	●						●	●		●	●		●	●		
F	1	●					●	●					●				●		●		●		QUALITATIVE RTO VALIDATION
	2	●					●	●					●				●		●			●	
	3	●					●	●					●				●	●	●		●		
	4	●					●	●						●			●	●	●		●		
	5	●					●		●				●				●	●	●		●		
	6	●					●		●					●			●	●	●		●		
	7	●					●					●		●			●		●			●	
	8	●					●					●		●			●		●		●		
	9	●					●					●		●			●		●		●		
	10	●					●					●		●			●		●			●	
	11	●					●				●		●				●		●			●	
	12	●					●				●		●				●		●		●		
G	1				●		●	●					●						●		●		QUALITATIVE TURN EVALUATION
	2				●		●	●					●						●			●	
	3				●		●	●					●						●		●		
	4				●		●	●					●						●			●	
H	1	●				●		●					●				●		●		●		FAMILIARIZATION FOR DEMONSTRATION AND POST DEMONSTRATION
	2A	●					●	●					●				●		●		●		
	2B	●					●	●					●				●		●			●	
	3A	●					●		●				●				●		●		●		
	3B	●					●		●				●				●		●			●	
	4	●					●		●				●				●	●	●		●		
	5A		●				●	●					●				●		●		●		
	5B		●				●	●					●				●		●			●	
	6		●				●	●						●			●		●		●		
	7		●				●		●					●			●		●		●		
	8		●				●		●					●			●	●	●		●		
I	1		●			●		●					●				●	●	●		●		DEMONSTRATION APPROACH AND LANDING WITH DIGITAL ANTISKID
	2		●			●		●						●			●	●	●		●		
	3		●			●		●						●	●		●	●	●		●		
	4		●				●	●					●				●	●	●		●		
	5		●				●	●						●			●	●	●		●		
	6		●				●	●						●			●		●		●		
	7		●				●		●				●				●	●	●		●		
	8		●				●		●					●			●	●	●		●		

TABLE 5-2 (Continued)

FLIGHT CARD TEST CONDITIONS

CARD	RUN NO.	RUN TYPE				PROFILE		RUNWAY CONDITION					WINDS			DECEL			MOTION		A/S		CARD OBJECTIVES
		RTO	LDG	VMCG	TURN	SMOOTH	ROUGH	DRY	WET	FLOODED	SYM PATCHY	UNSYM PAT.	CALM	STEADY	GUSTS	NO BRAKES	BRAKES	REVERSERS	ON	OFF	DIGITAL	ANALOG	
I	9		●				●		●					●	●		●	●	●		●		DEMONSTRATION APPROACH AND LANDING WITH DIGITAL ANTISKID
	10		●				●		●					●			●		●		●		
	11		●				●				●		●				●	●	●		●		
	12		●				●				●			●			●	●	●		●		
	13		●				●				●			●	●		●	●	●		●		
	14		●				●				●			●			●		●		●		
	15		●				●					●	●				●	●	●		●		
	16		●				●					●		●			●	●	●		●		
	17		●				●					●		●	●		●	●	●		●		
	18		●				●					●		●			●		●		●		
	19		●				●			●			●				●		●		●		
	20		●				●			●				●			●		●		●		
	21		●				●			●				●	●		●		●		●		
	22		●				●			●				●	●		●	●	●		●		
	23		●				●	●						●	●		●	●		●	●		
	24		●				●		●					●	●		●	●		●	●		
	25		●				●				●			●	●		●	●		●	●		
	26		●				●					●		●	●		●	●		●	●		
	27		●				●			●				●	●		●	●		●	●		
J	1		●			●		●					●				●	●	●			●	DEMONSTRATION APPROACH AND LANDING WITH ANALOG ANTISKID
	2		●			●		●						●			●	●	●			●	
	3		●			●		●						●	●		●	●	●			●	
	4		●				●	●					●				●	●	●			●	
	5		●				●	●						●			●	●	●			●	
	6		●				●	●						●			●		●			●	
	7		●				●		●				●				●	●	●			●	
	8		●				●		●					●			●	●	●			●	
	9		●				●		●					●	●		●	●	●			●	
	10		●				●		●					●			●		●			●	
	11		●				●				●		●				●	●	●			●	
	12		●				●				●			●			●	●	●			●	
	13		●				●				●			●	●		●	●	●			●	
	14		●				●				●			●			●		●			●	
	15		●				●					●	●				●	●	●			●	
	16		●				●					●		●			●	●	●			●	
	17		●				●					●		●	●		●	●	●			●	
	18		●				●					●		●			●		●			●	
	19		●				●			●			●				●		●			●	

TABLE 5-2 (Continued)

FLIGHT CARD TEST CONDITIONS

CARD	RUN NO.	RUN TYPE: RTO	RUN TYPE: LDG	RUN TYPE: VMCG	RUN TYPE: TURN	PROFILE: SMOOTH	PROFILE: ROUGH	RUNWAY CONDITION: DRY	RUNWAY CONDITION: WET	RUNWAY CONDITION: FLOODED	RUNWAY CONDITION: SYM PATCHY	RUNWAY CONDITION: UNSYM PAT.	WINDS: CALM	WINDS: STEADY	WINDS: GUSTS	DECEL: NO BRAKES	DECEL: BRAKES	DECEL: REVERSERS	MOTION: ON	MOTION: OFF	A/S: DIGITAL	A/S: ANALOG	CARD OBJECTIVES
J	20		●				●			●				●			●		●			●	DEMONSTRATION APPROACH AND LANDING WITH ANALOG ANTISKID
	21		●				●			●				●	●		●		●			●	
	22		●				●			●				●	●		●	●	●			●	
	23		●				●	●						●	●		●	●		●		●	
	24		●				●		●					●	●		●	●		●		●	
	25		●				●				●			●	●		●	●		●		●	
	26		●				●					●		●	●		●	●		●		●	
	27		●				●			●				●	●		●	●		●		●	
K	1		●				●	●					●			●			●		●		POST DEMONSTRATION RUNS
	2		●				●	●					●				●		●		●		
	3		●				●	●					●				●		●			●	
	4		●				●	●					●				●	●	●		●		
	5		●				●	●					●				●	●	●		●		
	6		●				●	●						●			●		●		●		
	7		●				●	●						●	●		●		●		●		
	8		●				●		●					●			●		●		●		
	9		●				●			●				●			●		●		●		
	10		●				●				●			●			●		●		●		
	11		●				●					●		●			●		●		●		
	12		●				●					●		●			●		●			●	
	13	●					●	●					●				●		●		●		
	14	●					●	●					●				●		●			●	
	15	●					●	●					●				●	●	●		●		
	16	●					●	●						●			●	●	●		●		
	17	●					●		●				●				●	●	●		●		
	18	●					●		●					●	●		●	●	●		●		
	19	●					●					●	●				●		●		●		
	20	●					●					●	●				●		●			●	
	21	●					●					●		●	●		●		●		●		
	22				●		●	●					●						●		●		
	23				●		●	●					●						●			●	
	24		●				●	●						●	●		●	●		●	●		
	25		●				●			●				●	●		●	●		●	●		
	26	●					●	●						●	●		●	●		●	●		
	27	●					●			●				●	●		●	●		●	●		
L	1	●					●		●					●			●	●		●	●		DEMONSTRATION RTO'S
	2	●					●		●					●			●	●		●		●	
	3	●					●	●					●				●		●			●	

TABLE 5-2 (Continued)

FLIGHT CARD TEST CONDITIONS

CARD	RUN NO.	RUN TYPE				PROFILE		RUNWAY CONDITION					WINDS			DECEL			MOTION		A/S		CARD OBJECTIVES
		RTO	LDG	VMCG	TURN	SMOOTH	ROUGH	DRY	WET	FLOODED	SYM PATCHY	UNSYM PAT.	CALM	STEADY	GUSTS	NO BRAKES	BRAKES	REVERSERS	ON	OFF	DIGITAL	ANALOG	
L	4	●					●	●					●				●		●		●		DEMONSTRATION RTO'S
	5	●					●	●						●			●		●		●		
	6	●					●	●						●			●		●			●	
	7	●					●	●						●	●		●		●			●	
	8	●					●	●						●	●		●		●		●		
	9	●					●	●						●	●		●	●	●		●		
	10	●					●	●						●	●		●	●	●			●	
	11	●					●		●				●				●		●			●	
	12	●					●		●				●				●		●		●		
	13	●					●		●					●			●		●		●		
	14	●					●		●					●			●		●			●	
	15	●					●		●					●	●		●		●			●	
	16	●					●		●					●	●		●		●		●		
	17	●					●		●					●	●		●	●	●		●		
	18	●					●		●					●	●		●	●	●			●	
	19	●					●			●			●				●		●			●	
	20	●					●			●			●				●		●		●		
	21	●					●			●				●			●		●		●		
	22	●					●			●				●			●		●			●	
	23	●					●			●				●	●		●		●			●	
	24	●					●			●				●	●		●		●		●		
	25	●					●			●				●	●		●	●	●		●		
	26	●					●			●				●	●		●	●	●			●	
	27	●					●			●			●				●			●		●	
	28	●					●			●			●				●			●	●		
M	1	●				●		●					●				●		●			●	DEMONSTRATION RTO'S
	2	●					●	●					●				●		●			●	
	3	●				●		●					●				●		●		●		
	4	●					●	●					●				●		●		●		
	5	●					●				●		●				●		●		●		
	6	●					●				●		●				●		●			●	
	7	●					●				●			●			●		●			●	
	8	●					●				●			●			●		●		●		
	9	●					●				●			●	●		●		●		●		
	10	●					●				●			●	●		●		●			●	
	11	●					●				●			●	●		●	●	●			●	
	12	●					●				●			●	●		●	●	●		●		
	13	●					●					●	●				●		●		●		

TABLE 5-2 (Continued)

FLIGHT CARD TEST CONDITIONS

CARD	RUN NO.	RUN TYPE				PROFILE		RUNWAY CONDITION					WINDS			DECEL			MOTION		A/S		CARD OBJECTIVES
		RTO	LDG	VMCG	TURN	SMOOTH	ROUGH	DRY	WET	FLOODED	SYM PATCHY	UNSYM PAT.	CALM	STEADY	GUSTS	NO BRAKES	BRAKES	REVERSERS	ON	OFF	DIGITAL	ANALOG	
M	14	●					●					●	●				●		●			●	DEMONSTRATION RTO'S
	15	●					●					●		●			●		●			●	
	16	●					●					●		●			●		●		●		
	17	●					●					●		●	●		●		●		●		
	18	●					●					●		●	●		●		●			●	
	19	●					●					●		●	●		●	●	●			●	
	20	●					●					●		●	●		●	●	●		●		
N	1	●			●	●		●					●				●		●			●	DEMONSTRATION SPECIAL MANEUVERS
	2	●			●		●	●					●				●		●			●	
	3	●			●		●	●					●				●		●			●	
	4	●			●		●	●					●				●		●			●	
	5	●			●		●	●					●				●		●			●	
	6		●				●			●				●			●		●			●	
	7		●				●			●				●			●		●			●	
	8		●				●			●				●			●	●	●			●	
	9		●				●			●				●			●		●		●		
	10		●				●			●				●			●		●		●		
	11		●				●			●				●			●	●	●		●		
	12		●				●		●				●				●		●		●		
	13		●				●		●				●				●		●			●	
	14				●		●		●				●			●			●			●	
	15				●		●			●			●			●			●			●	
	16				●		●		●				●			●			●		●		
	17				●		●			●			●			●			●		●		
O	1		●				●	●					●				●		●		●		FAMILIARIZATION RUNS FOR POST DEMONSTRATION
	2		●				●	●					●					●	●		●		
	3		●				●	●					●				●	●	●		●		
	4		●				●	●					●				●		●		●		
	5		●				●	●					●				●		●		●		
	6		●				●	●						●			●		●		●		
	7		●				●	●						●			●		●			●	
	8		●				●		●					●			●		●			●	
	9		●				●		●					●			●		●		●		
	10	●					●	●						●	●		●	●	●		●		
	11	●					●	●						●	●		●	●	●			●	
	12	●					●		●					●	●		●		●			●	
	13	●					●		●					●	●		●		●		●		
P	1		●				●	●					●				●	●		●	●		

TABLE 5-2 (Concluded)

FLIGHT CARD TEST CONDITIONS

CARD	RUN NO.	RUN TYPE: RTO	RUN TYPE: LDG	RUN TYPE: VMCG	RUN TYPE: TURN	PROFILE: SMOOTH	PROFILE: ROUGH	RUNWAY CONDITION: DRY	RUNWAY CONDITION: WET	RUNWAY CONDITION: FLOODED	RUNWAY CONDITION: SYM PATCHY	RUNWAY CONDITION: UNSYM PAT.	WINDS: CALM	WINDS: STEADY	WINDS: GUSTS	DECEL: NO BRAKES	DECEL: BRAKES	DECEL: REVERSERS	MOTION: ON	MOTION: OFF	A/S: DIGITAL	A/S: ANALOG	CARD OBJECTIVES
P	2		●				●	●					●				●	●	●		●		POST DEMONSTRATION RUNS
	3		●				●	●					●				●		●		●		
	4		●				●	●					●				●		●			●	
	5		●				●	●						●	●		●	●	●			●	
	6		●				●	●						●	●		●	●	●		●		
	7		●				●		●				●				●		●		●		
	8		●				●		●				●				●		●			●	
	9		●				●		●					●			●	●	●			●	
	10		●				●		●					●			●	●	●		●		
	11		●				●				●			●			●		●		●		
	12		●				●				●			●			●		●			●	
	13		●				●					●		●			●		●			●	
	14		●				●					●		●			●		●		●		
	15		●				●			●				●			●		●		●		
	16		●				●			●				●			●		●			●	
	17		●				●			●				●	●		●		●			●	
	18		●				●			●				●	●		●		●		●		
	19	●					●		●					●			●	●	●		●		
	20	●					●		●					●			●	●	●			●	
	21	●					●			●				●			●		●			●	
	22	●					●			●				●			●		●		●		
	23	●					●			●				●			●	●		●	●		

TABLE 5-3

SUMMARY OF RDC PILOT RUNS

PILOT	CHECKOUT	VALIDATION FLIGHT CARDS								DEMONSTRATION FLIGHT CARDS					POST DEMONSTRATION FLIGHT CARDS				TOTAL
		A	B	C	D	E	F	G	H	I	J	L	M	N	H	K	O	P	
Jansen	49																		49
Knickerbocker	9	4			8	12	13	4											50
Lyddane	48		12	10		14	12	4											100
Wiebr[illegible]ht									13	28	24	28	21	22					136
Tymczyszyn									12	27	25	32	24	27					147
Deal															11	27			38
Southerland															12	27			39
Armstrong															13	14			27
Weinert																	13	26	39
Altree																	13	25	38
Nucci																	13	28	41
Passingham																	13	25	38
Erdman																	14	22	36
Bugbee																	13	27	40
TOTAL	106	93								283					336				818

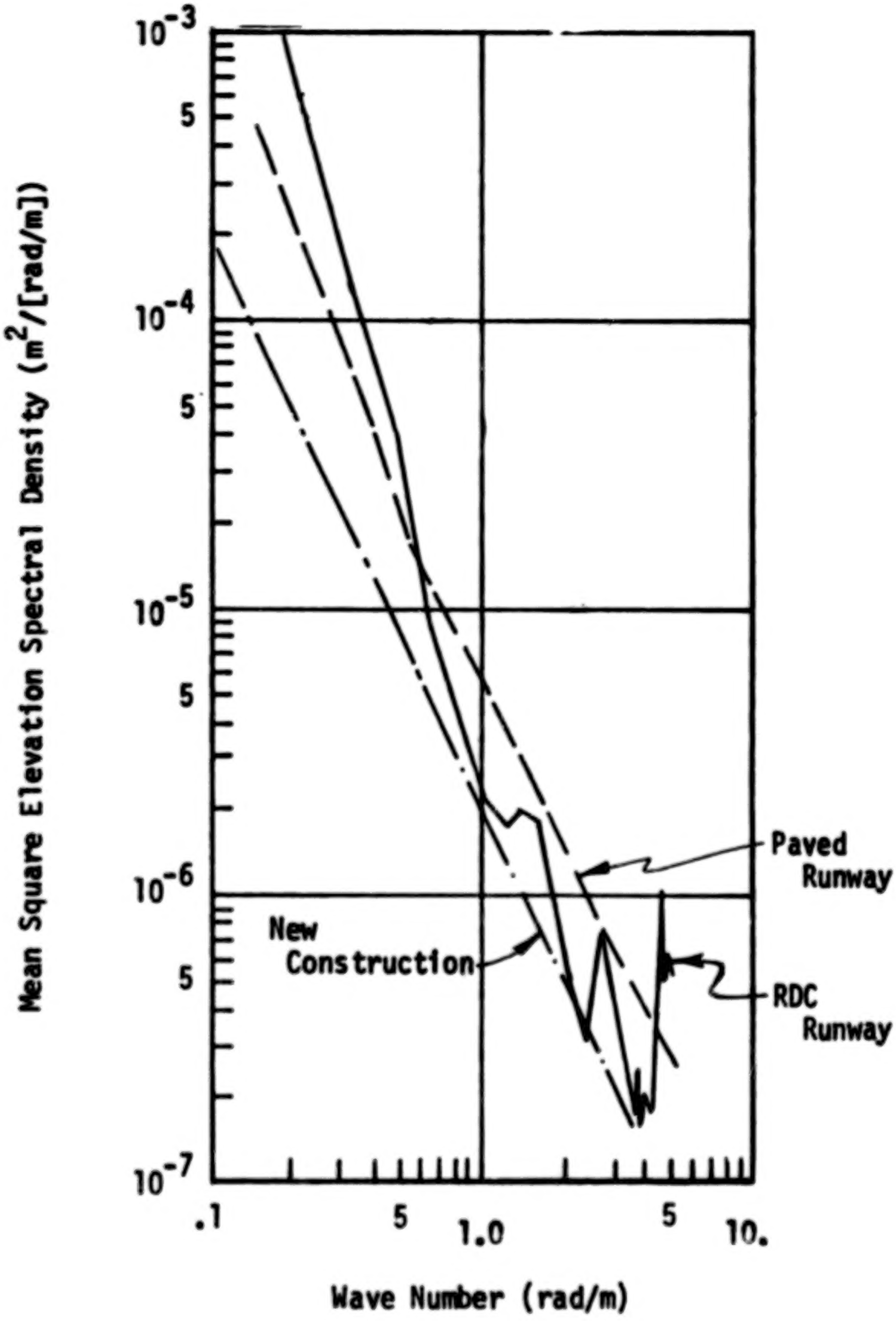


FIGURE 5-3 POWER SPECTRAL DENSITY OF RUNWAY USED IN RDC SIMULATION

TABLE 5-4

PERFORMANCE AREAS CHECKED DURING VALIDATION PHASE

CONDITION	PURPOSE	COMPARISON DATA	APPLICABLE FLIGHT CARDS	
			DIGITAL ANTISKID	ANALOG ANTISKID
MINIMUM CONTROL SPEED GROUND-V_{MCG}	QUANTITATIVE CHECK OF LATERAL GROUND HANDLING CHARACTERISTICS	REFERENCE 10	B	C
LANDING DISTANCE ANTISKID BRAKING FULL SPOILERS	QUANTITATIVE CHECK OF LONGITUDINAL GROUND PERFORMANCE	REFERENCE 6	D	D
APPROACHES, LANDINGS, RTO'S, TURNS	QUALITATIVE EVALUATION OF AIRCRAFT HANDLING QUALITIES	PAST PILOT EXPERIENCE	E,F,G	E,F,G

6.0 RESULTS AND DISCUSSION

6.1 CHECKOUT RUNS

6.1.1 Checkout Summary

During the checkout phase several changes to the simulator were implemented. In the final configuration, the nose gear steering sensitivity and time constant were acceptable, the cockpit motion with the analog antiskid was acceptable, and the cockpit motion with the digital antiskid was satisfactory. The V_{MCG} test results were acceptable. The digital antiskid dry stop distances were shorter than the actual aircraft flight test data and the analog antiskid dry results were longer. The subsystem checkouts of the aero software and antiskid were acceptable.

6.1.2 V_{MCG} Tests

The V_{MCG} test results obtained at the conclusion of the checkout phase are plotted in Figure 6-1. These results were obtained during no-motion operation with a non-test pilot. It was anticipated (and later proven) that the performance would be better during the validation phase where motion would be active and a test pilot would perform the test.

6.1.3 Deceleration Performance

Distance based average decelerations from brakes-on are tabulated in Table 6-1. For the dry runs, the digital results were better than the aircraft and the analog results were not as good as the aircraft. The digital performance improved slightly with runway roughness while the analog performance degraded significantly. This trend was also observed for the wet runs.

For the wet runs both the digital and analog performed better than the aircraft. The reason for this is that the friction coefficients experienced by the aircraft were lower than those used in the simulation.

For this condition both antiskid simulations used the damp results from Reference 5.

The damp condition was achieved by sweeping the standing water from the track. However, for the aircraft tests, there was standing water on the pavement surface. The average measured water depth for these runs was .064 cm (.025 inch).

During the checkout phase the pilots commented that the motion experienced in the cockpit with the analog antiskid was not as violent as it was in the aircraft. These comments persisted even after a change had been made to the analog simulation to make the operation more abrupt.

To investigate these pilot comments relative to cockpit motion, computer generated longitudinal accelerations were recorded and compared to measured aircraft longitudinal accelerations. This comparison is shown in Figure 6-2. The accelerations of both the analog and digital simulations were much more violent than the aircraft. This suggested that the simulator cockpit motion may not be strong enough. This possibility was verified subsequently during the post demonstration phase when motion base cockpit floor accelerations were analyzed. These results are discussed in Section 6.4.2.

6.2 VALIDATION RUNS

6.2.1 Summary of Validation Results

The V_{MCG} results were acceptably related to flight test results for both the digital and analog antiskid simulations. The deceleration performance exhibited the same trends as noted in the checkout phase. The averaged ratings for each category ranged from 2 to 4 for landings and RTO's. Both pilots commented that the nose gear steering was too insensitive, that wind response was not as expected, and that no motion degraded the simulation. After the validation runs, the nose gear steering was changed to make it more sensitive.

6.2.2 Quantitative Data Correlation

The V_{MCG} results for the digital and analog antiskid simulations are shown in Figures 6-3 and 6-4. Both sets of data showed relatively large deviations from the faired aircraft data at 90 knots with the higher power setting. This is due to pilot technique. The time between the throttle chop and hardover rudder application was 1/2 second for the analog run that correlated well and 1-3/4 second for the analog run that did not correlate well. For the digital simulation the corresponding time was 1-1/2 second. The corresponding time for the actual flight test averaged 1/2 second for all runs.

The deceleration results are plotted in Figures 6-5 and 6-6. The data is plotted as distance to stop versus velocity squared. With these coordinates, constant deceleration plots as a straight line. The digital dry results correlated well. The dry analog results do not correlate as well with the aircraft. This is probably due to the change that was made to the analog antiskid to make the cockpit longitudinal motion rougher. The change made to the u-slip curve to make the operation rougher, also made the antiskid operation more inefficient.

Both the digital and analog antiskid performance for the wet condition resulted in shorter stopping distance than the actual flight test performance for the same reason discussed in the checkout section. Both simulations also showed the same trends with runway roughness as was exhibited during the checkout phase.

6.2.3 Qualitative Pilot Evaluation

The validation pilots evaluated the simulation qualitatively for approach and landings and RTO's. The rating criteria shown in Figure 6-7 was used. The ratings are tabulated in Tables 6-2 and 6-3.

In Table 6-2 Lyddane rated the wind low on run 7 because he felt the gust model was not realistic. He also rated braking deceleration on the same run low because there was no sound cue for thrust reverse. Knickerbocker rated runway roughness low on run 12 because it was a no motion run which he felt was unrealistic.

In Table 6-3 Lyddane rated braking deceleration poor on run 7 because the aircraft went off the end of the runway. During these runs the spoiler handle signal did not cause spoiler deployment. Thus when the pilot actuated the spoiler handle, the lift was not killed and only low brake forces could be developed. This caused long aircraft runouts. Knickerbocker commented that the result would be expected if spoilers did not deploy.

The pilots who took part in the program made numerous comments during the runs. A summary of the often repeated comments and those that provided insight are listed in Table 6-4. Note that both validation pilots (A and B) agreed that the directional control and/or steering time constant was too long. They also both commented that the weathercocking and/or wind response was not as expected and that no motion degraded the simulation.

The pilots' responses to the questionnaire mentioned in section 5.1 are tabulated in Table 6-5. Knickerbocker commented that the antiskid cycling effect was not strong enough and that the visual display gave the sensation of skidding sideways.

6.3 DEMONSTRATION RUNS

6.3.1 Summary of Demonstration Results

The demonstration pilots' qualitative average ratings were as follows: control during approach - 3.5, ground directional control - 4.9, runway roughness - 2.5, braking deceleration - 4.9, and visual - 3.7. Both pilots commented that there was an unexpected aircraft response at 61 meters (200 feet) altitude, that the low speed wet friction coefficients should be greater, that no motion degrades the simulation, and that the

visual display gave the impression of skidding sideways. It was verified that stop distance with the analog antiskid degrades with increasing runway roughness. Also, with the analog antiskid on flooded runways, the wheels would completely lock up and cause loss of directional control.

6.3.2 Pilot Qualitative Evaluation

The demonstration pilot qualitative ratings are tabulated in Table 6-6. The categories of ground directional control and braking deceleration are rated low. The pilots' comments serve to explain their objections.

Comments regarding directional control:

Wiebracht - "Directional control at speeds below 80 knots is 'loose'. Initial rudder input (nose steering) is not met with an appropriate response - more input results in too much response and overcontrolling."

Tymczyszyn - "Friction coefficient too low at speeds below 90 knots wet and/or flooded - apparent by heading control lag and seems a function of rudder only - either that or excessive lag in visual drive system."

Comments regarding braking response:

Wiebracht - "Braking response good on dry/wet runways but in the low speed regime when brakes would become effective on a wet or even flooded runway, the feeling is one of sliding on ice."

Tymczyszyn - "Friction coefficient unrealistically low below 90 knots wet or flooded."

6.3.3 Typical Simulation Runs

Typical data that was recorded during the demonstration is presented in Figures 6-8 thru 6-15. Data for RTO's are given in Figures 6-8 thru 6-11. Figures 6-12 thru 6-15 present data for typical landings. The RTO's can be broken down into three parts: the initial portion of the run is where the power is set, the second phase is the acceleration portion, and then

the deceleration phase. The landings are characterized by an approach and impact followed by the rollout with deceleration.

In the RTO of Figure 6-8 note how at 50 seconds the brake pedal position traces show that the pilot modulated the brakes. The Left MLG Drag Load shows that the antiskid quit cycling at this point.

In Figure 6-9 the pilot did not modulate the brakes. Note how the Left MLG Drag Load shows releases followed by a gradual reapplication of pressure. This is characteristic of the analog antiskid simulation and is contrasted with the digital simulation that has a full application followed by a full release cycle. The c.g. longitudinal acceleration trace was inoperative for this run.

Figures 6-10 and 6-11 are thrust reverser runs with reverse thrust applied at 35 and 42 seconds respectfully. Both runs show a definite reduction in c.g. longitudinal acceleration when the thrust reverse is removed.

For the landings, the Distance Beyond Touchdown traces all show initial deflections prior to touchdown. The trace is reset to zero at touchdown and reads correctly throughout the remainder of the run. This is a characteristic of the way in which the parameter was calculated.

Note in Figure 6-15 that on the flooded runway (water depth 1 cm [.4 inch]), hydroplanning occurred at the beginning of the run and the wheels did not spin-up throughout the run. This reduced the cornering force to zero. The digital antiskid does not exhibit this lockup characteristic. Test data in References 5 and 6 show that this will occur if there is enough water on the runway.

6.3.4 <u>Special Runs (Flight Card N)</u>

Runs were made to investigate the effect of runway roughness on the analog simulator on stop performance that was apparent during the checkout and validation runs. A series of analog antiskid RTO's were made with variable runway roughness. On each run the pavement profile was multiplied

by a constant. The constant ranged from zero to 2.5. Standard roughness for the program was 2.0.

The results of these tests are presented in Figure 6-16 and show a definite trend of decreasing performance with increasing roughness. The reason for this is that the antiskid responds quickly to a skid and then slowly reapplies brake pressure. On a rough runway the tire normal load oscillates about the mean and the skid is more apt to happen when the load is light. The antiskid then reduces the pressure and as the pressure is reapplied slowly, it cannot take advantage of the time when the normal load is high.

As noted in Figure 6-15, the analog antiskid simulation would not prevent wheel lockups on flooded runways when full brake pressure was applied. This condition would lead to directional control problems because of the loss of tire cornering force. A series of RTO's were made to investigate how pilots cope with this condition. The pilot made the run first using maximum brake application. The next run was with the pilot modulating the brakes. The next run was brake modulation and thrust reverse. There was a steady 15 kts cross wind for all runs. Both analog and digital antiskid simulations were used.

The results are tabulated in Table 6-7. The normal braking technique produced smaller deviations from the runway centerline and smaller heading deviations than the maximum braking technique. The average decelerations were about the same. Use of thrust reversers resulted in less centerline deviation but larger heading deviations. The deceleration with thrust reverse was significantly better than with brakes only.

To show the performance degradation that results when spoilers do not deploy, landings were made without spoiler deployment on a wet runway to compare to similar landings with spoilers. The results showed that when the spoilers were not deployed, the aircraft deceleration was reduced by 33 percent with the digital antiskid simulation and 42 percent with the analog.

All pilots who took part in this program were asked to complete the opinion form shown in Figure 5-2. The summary of the results is shown in Table 6-8. Wiebracht commented that there is considerable training benefit with the simulator as is. He recommended extensive revisions in applications 5, 6, and 7 in order to incorporate accurate quantitative data.

6.4 POST DEMONSTRATION RUNS

6.4.1 Summary of Post Demonstration Runs

The post demonstration pilots rated the simulation as follows: Control during approach 3.8, Ground directional control 3.6, Braking deceleration 3.0, Visual 3.7, Motion 3.0. The pilots' comment most often made was that no motion degraded the simulation.

6.4.2 Pilot Evaluation

The qualitative numerical ratings are tabulated in Table 6-9. These ratings are summarized in Table 6-10, with the operational pilots listed separately from the non-operational pilots. The operational pilots rated the simulator better in the areas of control during approach, ground directional control, and braking deceleration.

Comments expressed by at least two line pilots during the runs concerned the following areas:

During approach - Abnormal requirement of pitch change at 61 meters (200 feet). Depth perception deficient below 15.2 meters (50 feet).

On the ground - Directional control good but too sensitive at low speed. Wind effects on handling apparent. Runway roughness was realistic. Lateral motion was deficient. No motion degraded the simulation. The digital antiskid brake cycling was apparent and was a good representation for dry braking.

It is interesting to note that the comment about weathercocking or wind response not being as expected made several times by many pilots was not made by a line pilot.

The post demonstration pilots' responses to the NASA questionnaire are included in Table 6-5. All pilots felt the vertical field of view was sufficient. Most thought that the horizontal field of view was adequate although a number mentioned that peripheral vision cues would help. The fixed focus was of little concern. Most felt that the visual scene did not give good altitude, sink rate, and flare cues. The majority of the pilots felt that motion improves sensing of deceleration and skid. Most felt that the lateral or longitudinal motion cues were deficient. Several noticed lags in the visual.

The post demonstration pilots' responses to the opinion form of Figure 5-2 are included in Table 6-8. Southerland expressing the FAA composite commented that proper directional control sensitivity is required in order to use the simulator to optimize pilot technique on adverse runways. The addition of sound is needed in order to use the simulator in training pilots for adverse runway conditions. Passingham remarked that the simulation appears to be a potential asset for training, especially on contaminated runways.

In order to investigate comments that the pilots were making relative to the cockpit motion deficiency with the analog antiskid, actual accelerations of the cockpit were recorded to compare with the theoretical computer generated accelerations and actual aircraft data. Figure 6-17 shows (a) aircraft longitudinal accelerations recorded during a maximum performance stop (Reference 6), (b) longitudinal accelerations calculated in the equations of motion for the simulation, and (c) actual simulator cockpit longitudinal accelerations. Bugbee was the pilot for these runs.

The cockpit accelerations for the digital antiskid are greater than those of the analog. The character of the computed digital acceleration is totally different than the aircraft. The character of the computed analog

acceleration is similar to the aircraft but the magnitude of the releases are too severe. There appears to be an acceleration reduction between the computer and the cockpit of about 5. Because of time restrictions, the reason for this result was not determined.

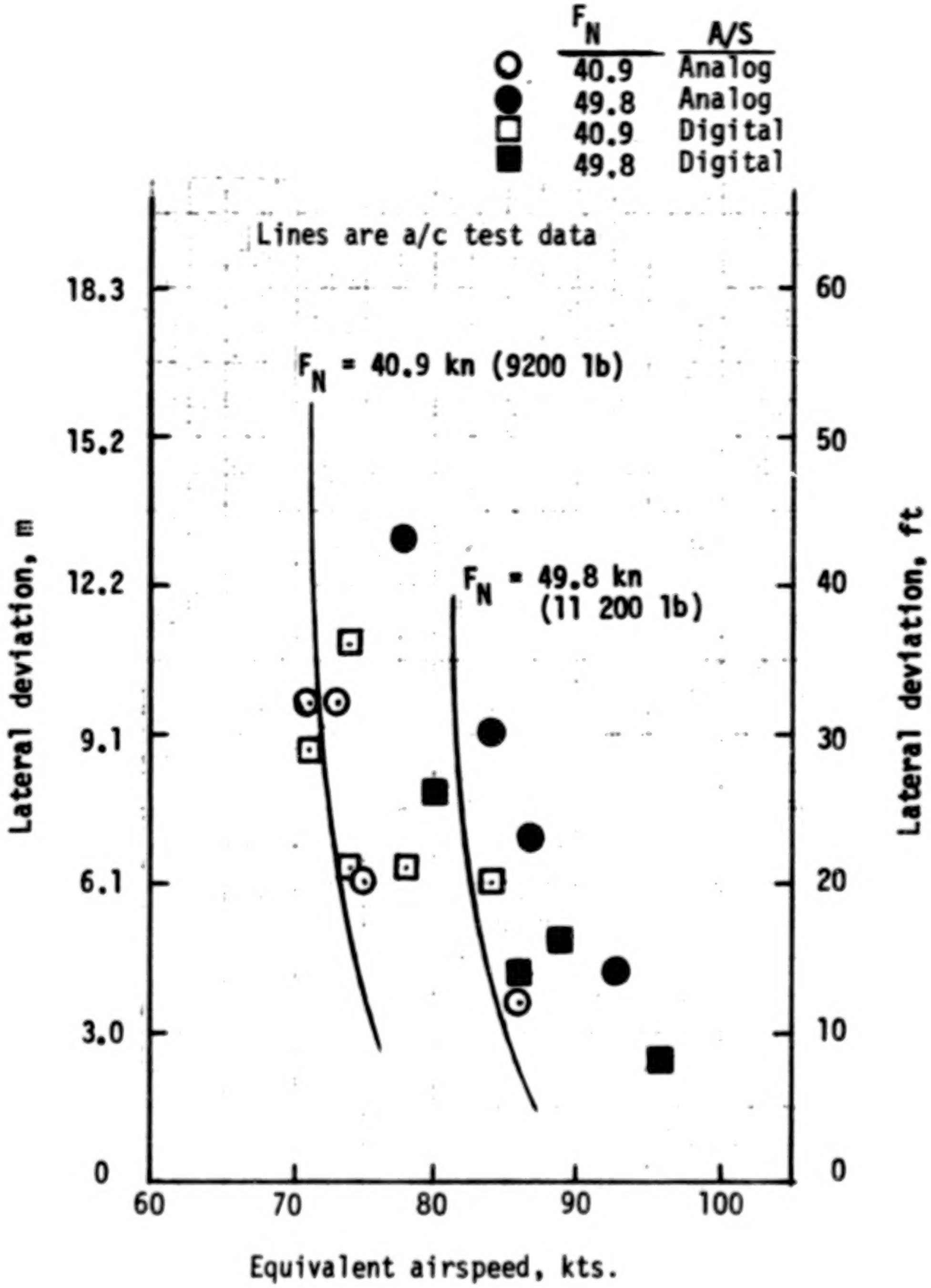


FIGURE 6-1 MINIMUM CONTROL SPEED GROUND (V_{MCG}) TEST, CHECKOUT PHASE

TABLE 6-1

CHECKOUT RESULTS

Distance based average decelerations between brakes-on and full stop

RUNWAY SURFACE CONDITION	AIRCRAFT RESULTS (REFERENCE 6)		SIMULATION RESULTS		
	RUN	DECEL M/SEC^2 (FT/SEC^2)	RUNWAY PROFILE	DIGITAL DECEL M/SEC^2 (FT/SEC^2)	ANALOG DECEL M/SEC^2 (FT/SEC^2)
Dry	62	3.87 (12.7)	Smooth	3.96 (13.0)	3.51 (11.5)
	63	3.75 (12.3)			
	64	3.69 (12.1)	Rough	4.02 (13.2)	2.83 (9.3)
	65	4.11 (13.5)			
Wet	66A	1.68 (5.5)	Smooth	2.26 (7.4)	2.13 (7.0)
	67	1.46 (4.8)			
	70	1.46 (4.8)	Rough	2.32 (7.6)	1.92 (6.3)
	71	1.52 (5.0)			

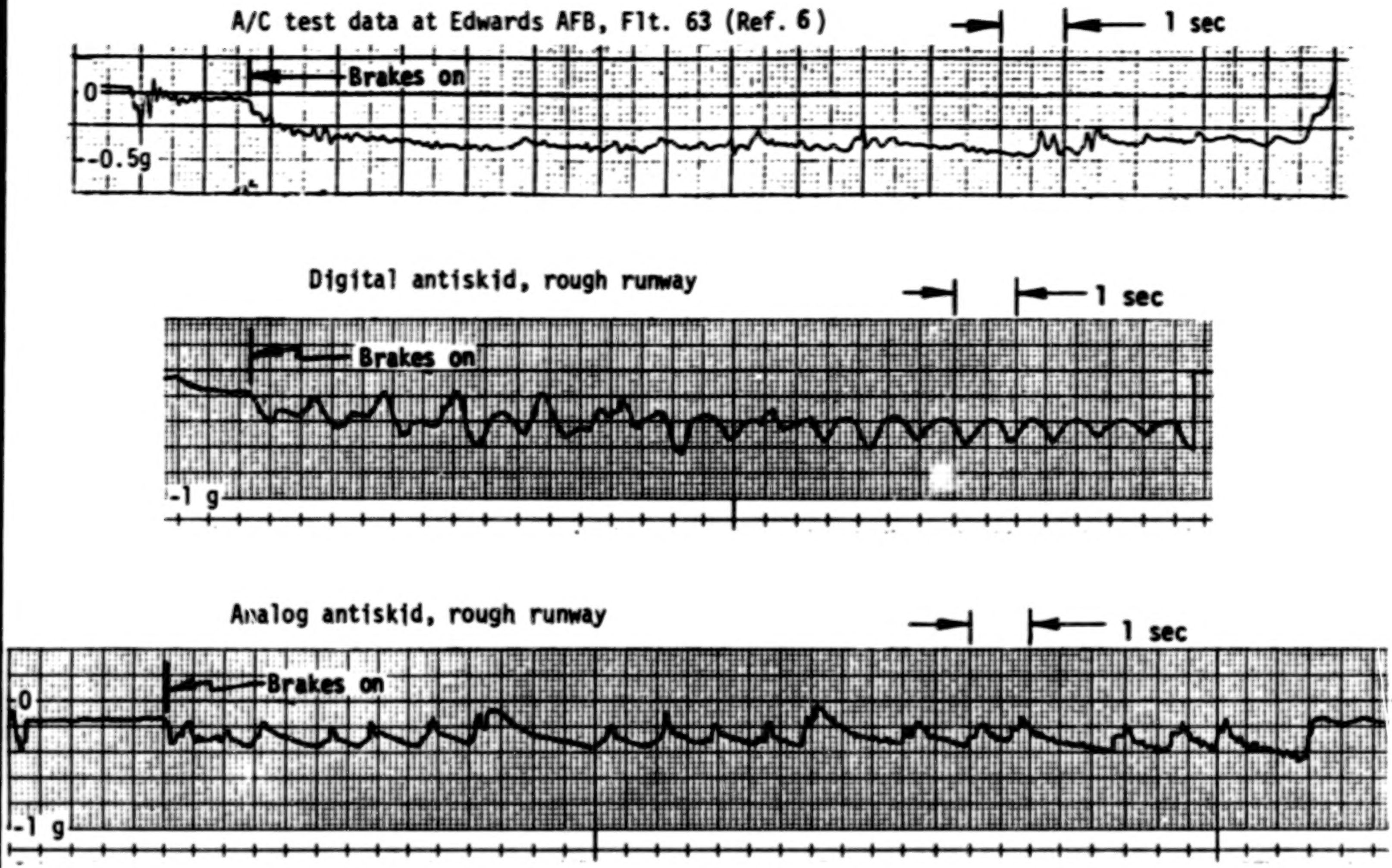


FIGURE 6-2 LONGITUDINAL ACCELERATION DURING BRAKING, CHECKOUT PHASE, COMPARED TO AIRCRAFT TEST DATA, DRY RUNWAY

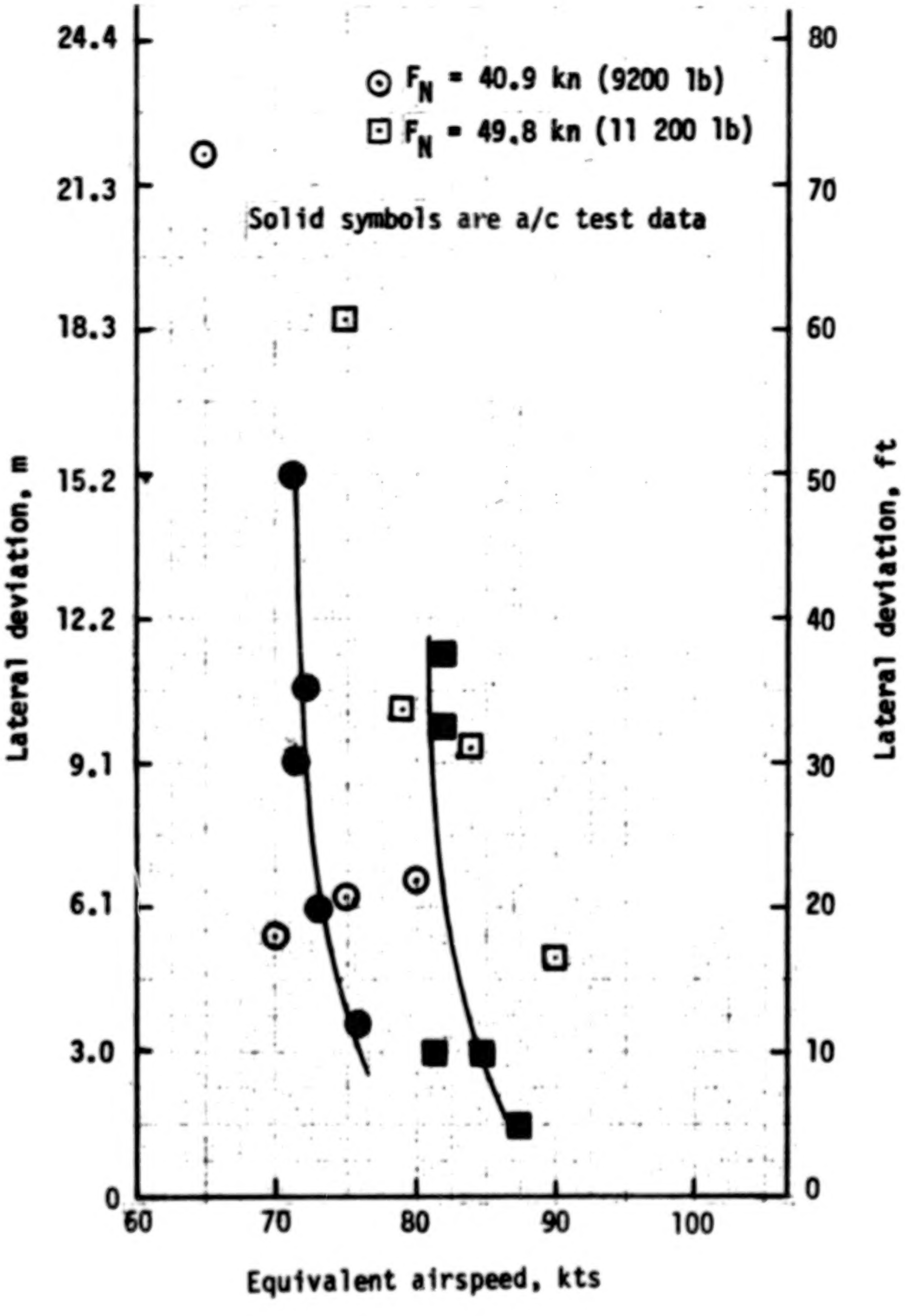


FIGURE 6-3 MINIMUM CONTROL SPEED GROUND (V_{MCG}) TEST, SIMULATOR VS AIRCRAFT TEST DATA, DIGITAL ANTISKID SYSTEM

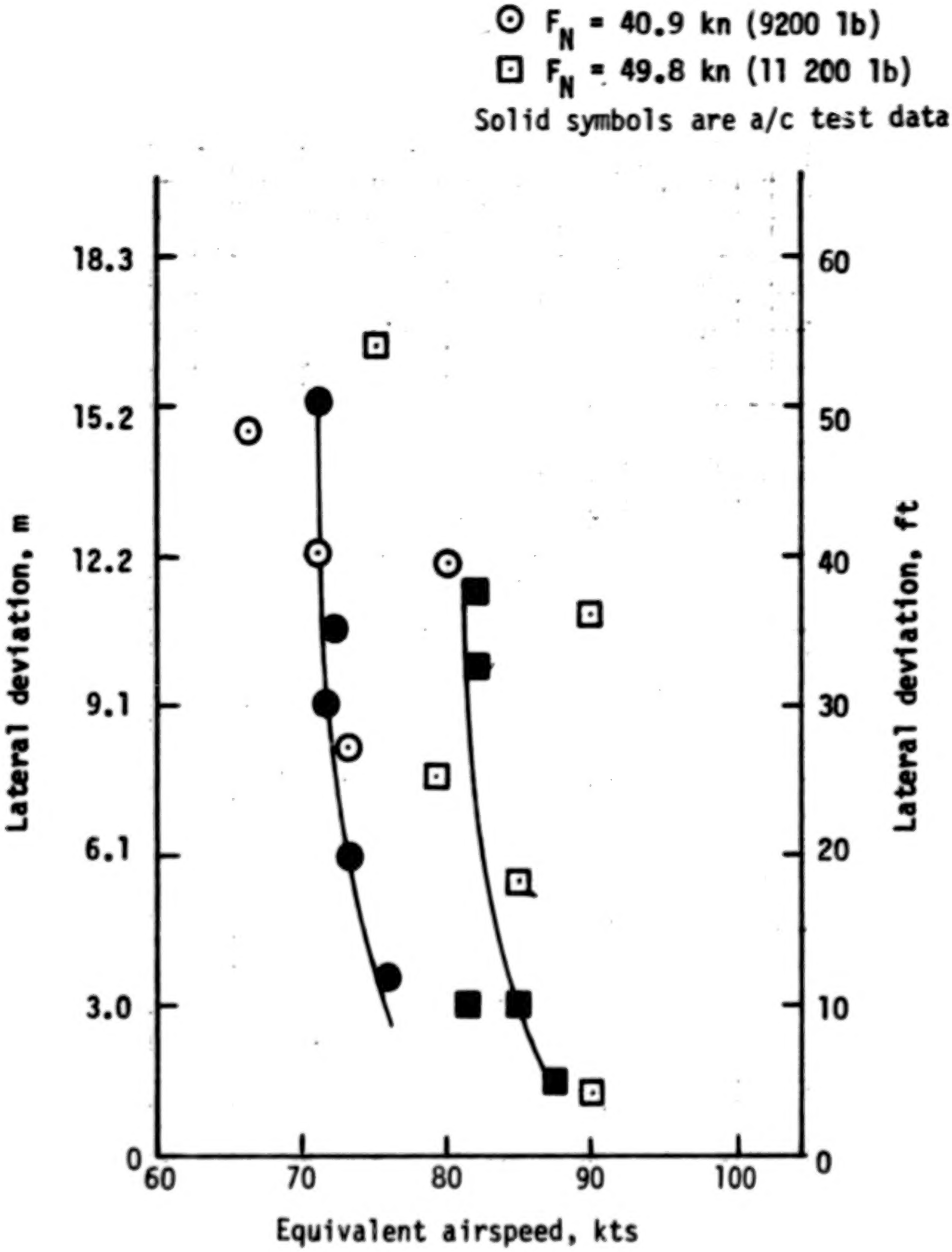


FIGURE 6-4 MINIMUM CONTROL SPEED GROUND (V_{MCG}) TEST, SIMULATOR VS AIRCRAFT TEST DATA, ANALOG ANTISKID SYSTEM

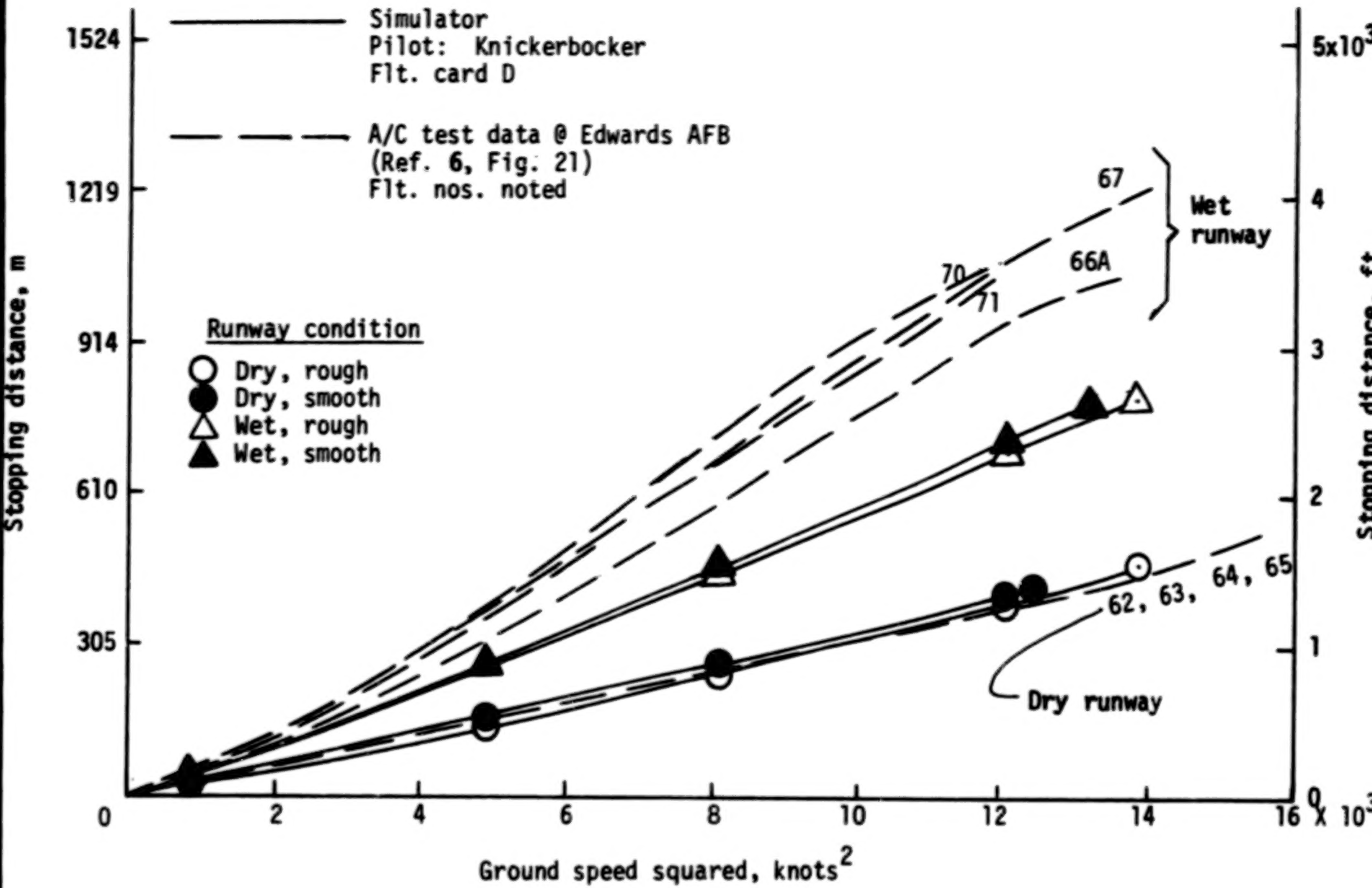


FIGURE 6-5 BRAKING PERFORMANCE, SIMULATOR VS. AIRCRAFT TEST DATA, LANDINGS, DIGITAL ANTISKID SYSTEM

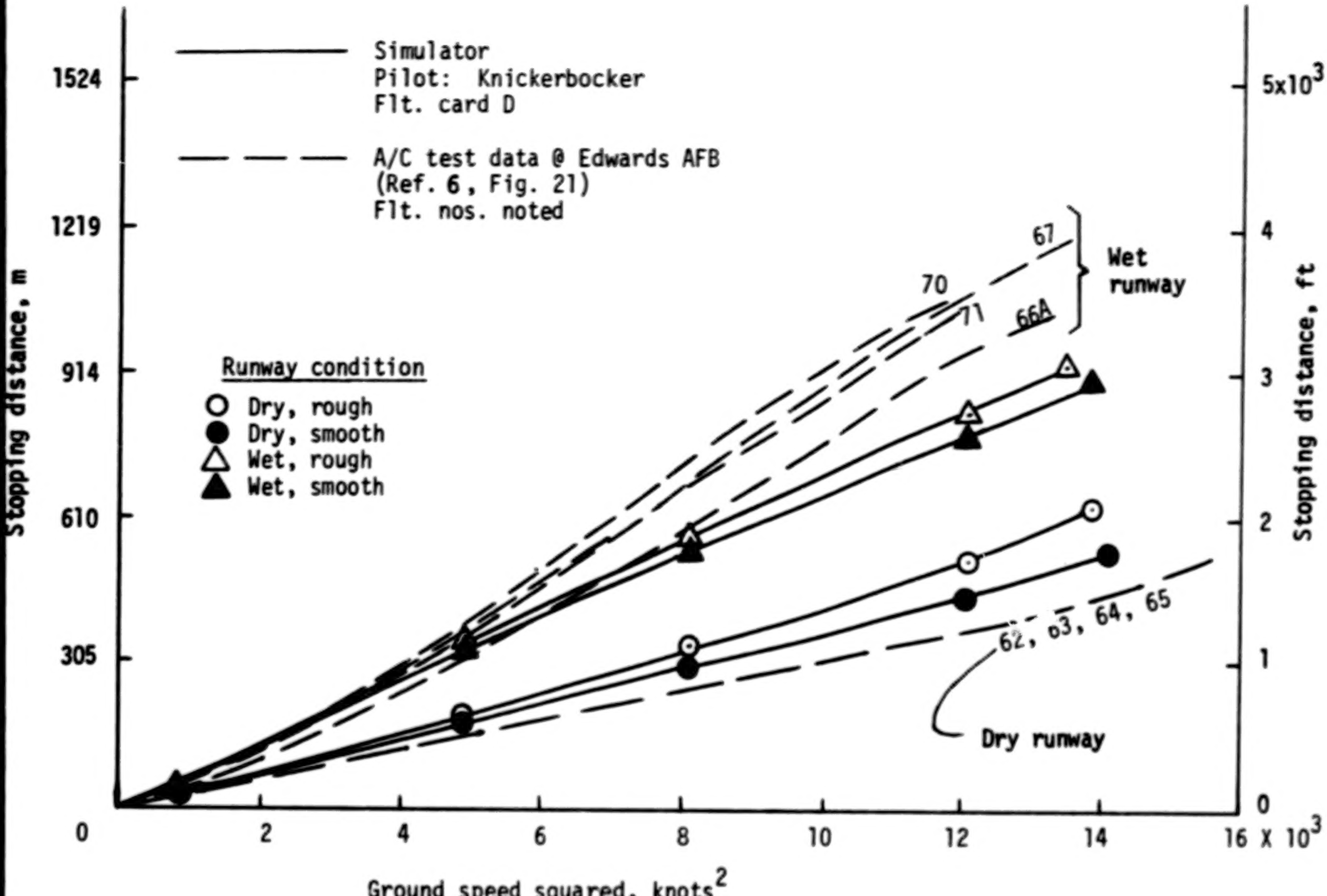


FIGURE 6-6 BRAKING PERFORMANCE, SIMULATOR VS. AIRCRAFT TEST DATA, LANDINGS, ANALOG ANTISKID SYSTEM

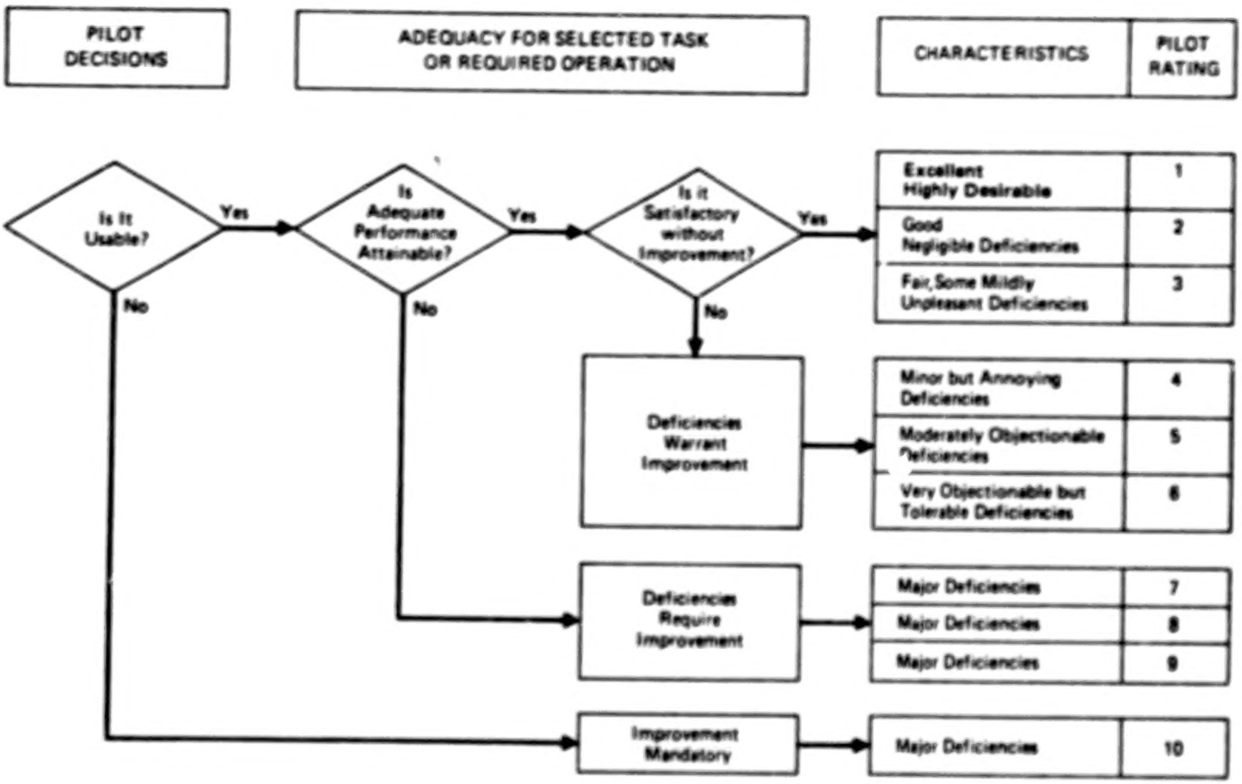


FIGURE 6-7 PILOT RATING CRITERIA

TABLE 6-2

VALIDATION PILOT QUALITATIVE RATINGS

FLIGHT CARD E: APPROACH AND LANDING

PILOT

A - KNICKERBOCKER
B - LYDDANE

RATING

1 - EXCELLENT
10 - POOR

	GROUND DIRECTIONAL CONTROL		WIND		RUNWAY ROUGHNESS		BRAKING DECELERATION		THRUST REVERSE		VISUAL		MOTION	
RUN \ PILOT	A	B	A	B	A	B	A	B	A	B	A	B	A	B
1	2	3			2	2					4	3	3	3
2	2	3			2	2	2	3			4	2	4	3
3	2	2			2	2	2	2			4	2	6	2
4	2				2	2	2	5	2	5	4	2	3	2
5	2	2			2	2	2	6	2	6	4	2	6	2
6	2	2	2	3	2	2	2	5	3	6	4	2	6	5
7	3	2	2	8	2	2	2	8	3	6	4	2		5
8	2	3			2	2	2	3	3	3	3	3	3	3
9	2	3	2	3	2	2	2	3			3	3	3	3
10	2	3	2	3	2	2	2	3			3	3	2	3
11	2	3	2	3	2	2	2	5			3	3	6	3
12	4		2		7		3		3		3			
AVERAGES	2.25	2.60	2.00	4.00	2.42	2.00	2.09	4.30	2.67	5.20	3.58	2.45	4.20	3.09
AVERAGES	2.43		3.00		2.21		3.20		3.94		3.02		3.65	

TABLE 6-3

VALIDATION PILOT QUALITATIVE RATINGS

FLIGHT CARD F: REJECTED TAKEOFF

PILOT

A - KNICKERBOCKER
B - LYDDANE

RATING

1 - EXCELLENT
10 - POOR

	GROUND DIRECTIONAL CONTROL		WIND		RUNWAY ROUGHNESS		BRAKING DECELERATION		THRUST REVERSE		VISUAL		MOTION	
RUN \ PILOT	A	B	A	B	A	B	A	B	A	B	A	B	A	B
1	2	3			2	2	2	3			3	3	2	3
2	4	3			3	2	4	4			3	3	3	3
3	4	3			2	2	2	3	3	5	3	3	2	3
4	4	2	2	2	2	2	2	4	3	5	3	3	2	3
5	4	2			2	2	2	4	3		3	3	2	3
6	5	2	2	2	2	2	2	4	3		3	3	2	3
7	5	2		2	2	2	2	9			3	3	2	3
8	5	2		2	2	2	2	4			3	3	2	3
9	5		2		2		2				3		2	
10	6		2		2		3				3		2	
11	4				2		2				3		2	
12	3				2		2				3		2	
AVERAGES	4.25	2.38	2.00	2.00	2.08	2.00	2.25	4.38	3.00	5.00	3.00	3.00	2.08	3.00
	3.32		2.00		2.04		3.32		4.00		3.00		2.54	

TABLE 6-4

PILOT COMMENT SUMMARY

COMMENT	A	B	C	D	E	F	G	H	I	J	K	L	M
	PILOT												
1. BENDING GLIDE SLOPE, WINDSHEAR, GROUND EFFECT, OR FLOAT AT 200 FT ALTITUDE			●	●			●	●	●	●			●
2. AIRCRAFT NOT TRIMMED, TRIM SLUGGISH, OR TRIM DIFFERENT THAN AIRCRAFT.			●					●				●	
3. AIRCRAFT TOO SENSITIVE TO PILOT CONTROL AND WIND DURING APPROACH.	●		●			●					●		
4. AIRCRAFT FLIGHT CHARACTERISTICS GOOD.											●	●	
5. DIRECTIONAL CONTROL INSENSITIVE OR TIME CONSTANT TOO LONG.	●	●											
6. DIRECTIONAL CONTROL TOO SENSITIVE.			●			●		●					●
7. DIRECTIONAL CONTROL TOO SENSITIVE AT LOW SPEED, ALRIGHT HIGH SPEED.									●		●	●	
8. DIRECTIONAL CONTROL TOO SENSITIVE DURING ACCELERATION, ALRIGHT DECELERATION.			●				●	●					
9. NOSE WHEEL STEERING IS TOO SENSITIVE.			●					●				●	●
10. AIRCRAFT RESPONSE TO WINDS ON RUNWAY TOO SENSITIVE.		●		●									●
11. DIRECTIONAL CONTROL GOOD.		●	●		●				●		●	●	
12. WEATHERCOCK OR WIND RESPONSE NOT AS EXPECTED.	●	●		●	●	●	●						
13. COULD FEEL EFFECT OF WINDS ON AIRCRAFT HANDLING.	●	●	●	●	●	●	●	●	●	●	●	●	●
14. WIND GUST MODEL NOT ADEQUATELY REPRESENTED.		●		●									
15. DIGITAL ANTISKID BRAKE CYCLING IS APPARENT.	●	●	●	●	●	●	●	●	●	●	●	●	●
16. DIGITAL ANTISKID GOOD REPRESENTATION FOR DRY BRAKING	●	●	●	●	●	●	●	●	●	●	●	●	●
17. DIRECTIONAL CONTROL OVERSHOOTS.	●		●			●							
18. WOULD USE STEERING TILLER.								●				●	
19. REALISTIC BRAKING.		●	●									●	
20. LOW SPEED WET COEFFICIENT SHOULD BE GREATER.			●	●									
21. GUSTS POOR.		●	●	●									
22. WINDS REALISTIC			●	●									●
23. ANTISKID TOO ROUGH OR TOO MUCH COCKPIT VERTICAL MOTION.		●	●								●		
24. JERKINESS OF DIGITAL ANTISKID MORE REALISTIC.		●		●				●		●		●	
25. BOTH ANTISKIDS NOT JERKY ENOUGH.	●					●				●			
26. FEELING OF PATCHY RUNWAY CONDITION IS GOOD.		●		●	●				●				●
27. ANALOG ANTISKID MORE APPROPRIATE FOR WET.	●		●	●				●					●
28. ROUGHNESS IS REALISTIC OR SMOOTHNESS IS UNREALISTIC.	●	●	●	●	●	●	●	●	●	●	●	●	●
29. EXPECT SMOOTHER RIDE FOR WET/FLOODED RUNWAY BRAKING.											●		●
30. THRUST REVERSE LEVER DETAIL NOT LIKE AIRCRAFT.	●								●				
31. THRUST REVERSE OPERATION SATISFACTORY.			●									●	
32. DECELERATION AT LOW SPEED IS NOT HIGH ENOUGH.			●	●		●	●				●		
33. NO MOTION DEGRADES THE SIMULATION.	●	●	●	●	●	●		●	●	●	●	●	●
34. TOO MUCH VERTICAL MOTION DURING BRAKING.			●								●		
35. LONGITUDINAL MOTION DEFICIENT.					●		●				●		
36. COULD NOT FEEL NOSE GEAR HIT.		●		●			●						
37. SOMETIMES COULD FEEL NOSE GEAR HIT, OTHER TIMES COULD NOT.	●				●		●	●					
38. DIGITAL ANTISKID FRICTION COEFFICIENT TOO HIGH FOR FLOODED RUNWAY.			●	●									
39. LATERAL MOTION IS DEFICIENT.			●					●	●		●		
40. VISUAL GIVES IMPRESSION OF SKIDDING SIDEWAYS.	●		●	●			●				●		●
41. PERIPHERAL DISPLAY WOULD HELP.					●			●	●				
42. DEPTH PERCEPTION OR VISUAL HEIGHT CUE DEFICIENT BELOW 50 FT.			●		●			●		●	●	●	●
43. VISUAL IMAGE IS FUZZY.			●					●					●
44. LAG IN VISUAL.			●				●						
45. VISUAL SPEED CUE VAGUE AT LOW SPEED.				●	●	●	●					●	
46. NOISE CUES WOULD HELP.		●		●	●	●	●			●	●		

TABLE 6-5

PILOT QUESTIONNAIRE SUMMARY

PILOT	VISUAL					MOTION		BOTH
	IS VERTICAL FIELD OF VIEW SUFFICIENT FOR GROUND HANDLING TASK? (YES / NO)	WHAT IS YOUR ASSESSMENT OF HORIZONTAL FIELD OF VIEW? (ADEQUATE / RESTRICTIVE)	HOW CRITICAL IS FIXED FOCUS? (ADEQUATE / NOT CRITICAL / NO COMMENT)	DOES VISUAL SCENE GIVE GOOD ALTITUDE, SINK RATE, AND FLARE CUES? (YES / NO)	DO MOTION CUES IMPROVE SENSING OF DECELERATION? (YES / NO)	DO MOTION CUES AID IN SENSING A SKID? (YES / NO)	WERE MOTION CUES OF SUFFICIENT MAGNITUDE? (YES / NO)	WERE THERE NOTICEABLE TIME LAGS IN EITHER VISUAL SCENE OR MOTION AND WERE THEY COORDINATED? (VISUAL YES/NO, MOTION YES/NO, COORD. YES/NO)
KRUEGER-BOCKER	YES	ADEQUATE	NOT CRITICAL	YES	YES	YES	NO. ANTISKID CYCLING EFFECT TOO SMALL.	VISUAL YES. SKIDDING SENSATION IN VISUAL.
WEEBRACHT	YES. CGI SYSTEM MAY HELP APPROACH ANGLE AND FLARE CUE.	RESTRICTIVE. CGI WOULD BE AN IMPROVEMENT.	NO COMMENT	NO. TOO FUZZY TO GIVE GOOD FLARE HEIGHT AND DRIFT CUE.	YES	NO. TOO SMALL LATERAL CUES.	YES. EXCEPT FOR LATERAL. ANTISKID GALLOPING TOO STRONG.	VISUAL NO, COORD. YES
TYCZYSZYN	YES	RESTRICTIVE. NEED PERIPHERAL VISION.	NOT CRITICAL	YES	YES	YES		COORD. YES
KEA	YES	ADEQUATE. NEED PERIPHERAL VISIBILITY FOR SPEED CUE.	NO COMMENT	NO. 2D CANNOT GIVE GOOD CUE.	YES. LONGITUDINAL "G" CUE WEAK.	YES. MORE APPARENT AFTER FIXED BASE OPERATION.	YES. EXCEPT FOR LONGITUDINAL "G".	VISUAL NO, MOTION NO, COORD. YES
SOUTHERLAND	YES	ADEQUATE	ADEQUATE	NO. ALTITUDE AND SINK RATE VAGUE. FLARE VERY GOOD.	YES	YES	NO. ANTISKID CYCLING WEAK.	
ARMSTRONG	YES	RESTRICTIVE. INADEQUATE FOR SPEED ASSESSMENT. PERIPHERAL CUES MAY HELP.	NOT CRITICAL	NO. ALTITUDE AND SINK RATE ADEQUATE. FLARE NOT AS GOOD.	YES. LONGITUDINAL "G" CUE WEAK.	NO	NO. NEED HIGHER FREQUENCY CAPABILITY.	VISUAL YES, COORD. YES
WEINERT	YES	RESTRICTIVE. ALSO LACK OF CLEAR CUT HORIZON IS DISCONCERTING.	ADEQUATE. MINOR ANNOYANCE.	YES. NO FEELING OF SINK RATE.	YES	YES. LATERAL "G" CUE MISSING.	NO. LATERAL "G" CUE MISSING.	
ALTREE	YES	ADEQUATE	NOT CRITICAL	YES. SINK RATE CUES HARD TO COME BY EVEN IN THE REAL WORLD.	YES	YES. ACTUAL ANTI-SKID IS MORE SEVERE.	YES	COORD. YES
RUCCI	YES	ADEQUATE. COULD BE IMPROVED.	NO COMMENT	NO	YES. INSUFFICIENT LONGITUDINAL "G" CUE.	YES. INSUFFICIENT LATERAL "G" CUE.	NO	VISUAL NO, MOTION NO
DUBREE	YES. VISUAL SCENE FUZZY.	ADEQUATE. WRAP AROUND VISION WOULD BE NICE.	ADEQUATE	NO. DON'T SEEM TO GET FEELING OF PERSPECTIVE.	YES	YES. POSSIBLY.	YES	VISUAL YES
PASSINGHAM	YES	ADEQUATE. INCREASED PERIPHERAL VISION IS DESIRABLE.	NO COMMENT	YES. VISUAL SCENE SOMEWHAT FUZZY.	YES. MOTION IS A MUST.	YES. MORE LATERAL "G" CUE NEEDED.	NO. SHOULD BE INCREASED.	VISUAL NO, MOTION NO, COORD. YES

TABLE 6-6

DEMONSTRATION PILOT QUALITATIVE RATINGS

PILOT

C - WIEBRACHT
D - TYMCZYSZYN

RATINGS

1 - EXCELLENT
10 - POOR

	CONTROL DURING APPROACH		GROUND DIRECTIONAL CONTROL		BRAKING DECELERATION		VISUAL	
CARD \ PILOT	C	D	C	D	C	D	C	D
I - LANDING DIGITAL ANTISKID	4	3	5	4.5	5	5	4	3
J - LANDING-ANALOG ANTISKID	4	3	6	4.5	6	5.5	4	3
L - RTO-DRY, WET, FLOODED			6	4.0	5	3.0	5	3
M - RTO-DRY PATCHY				3.5		4.5		3
	4.0	3.0	5.7	4.1	5.3	4.5	4.3	3.0
	3.5		4.9		4.9		3.7	

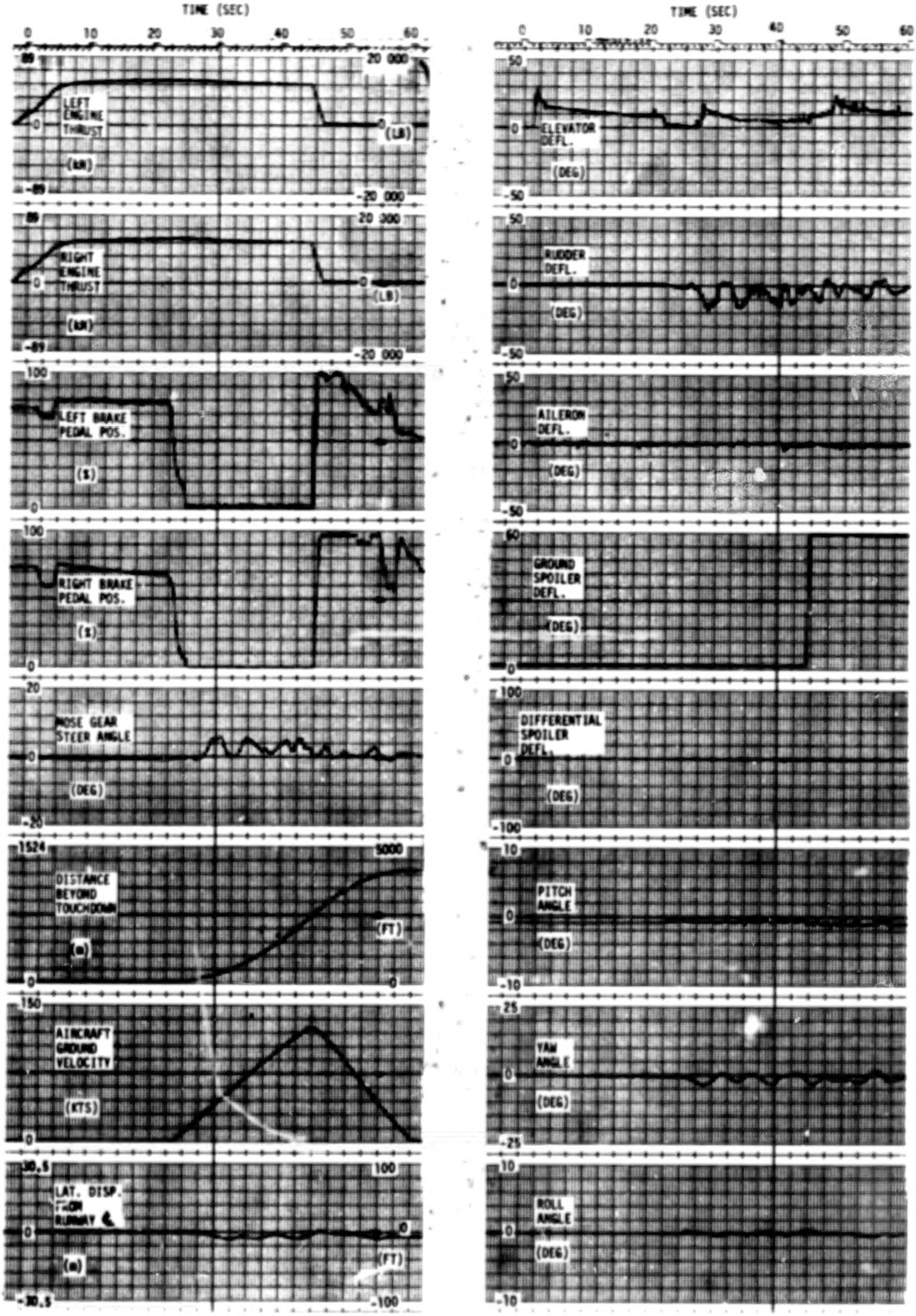


FIGURE 6-8 TYPICAL DRY RTO, BRAKES ONLY, DIGITAL ANTISKID, PILOT - WIEBRACHT, RUN-L8

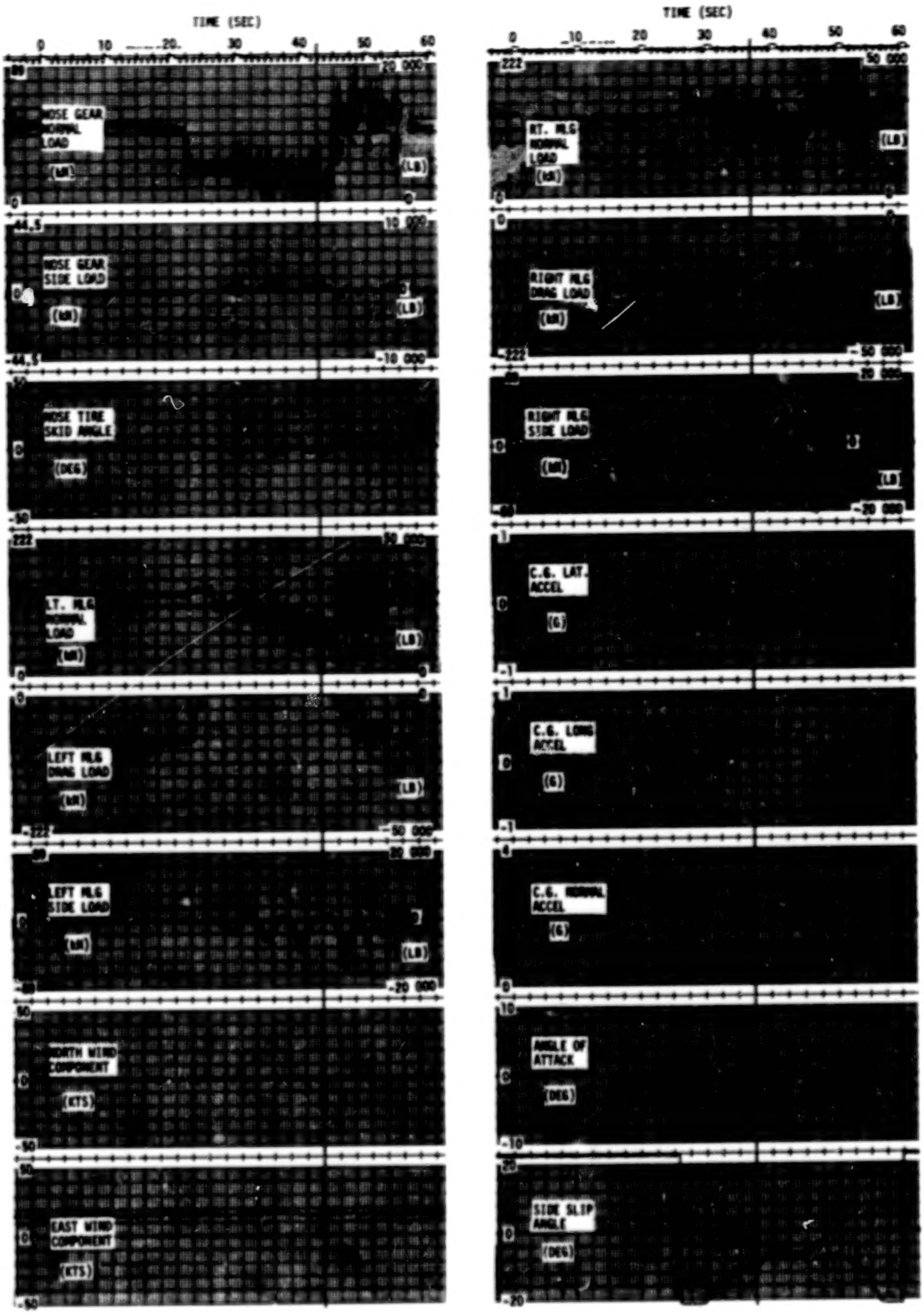


FIGURE 6-8 CONCLUDED

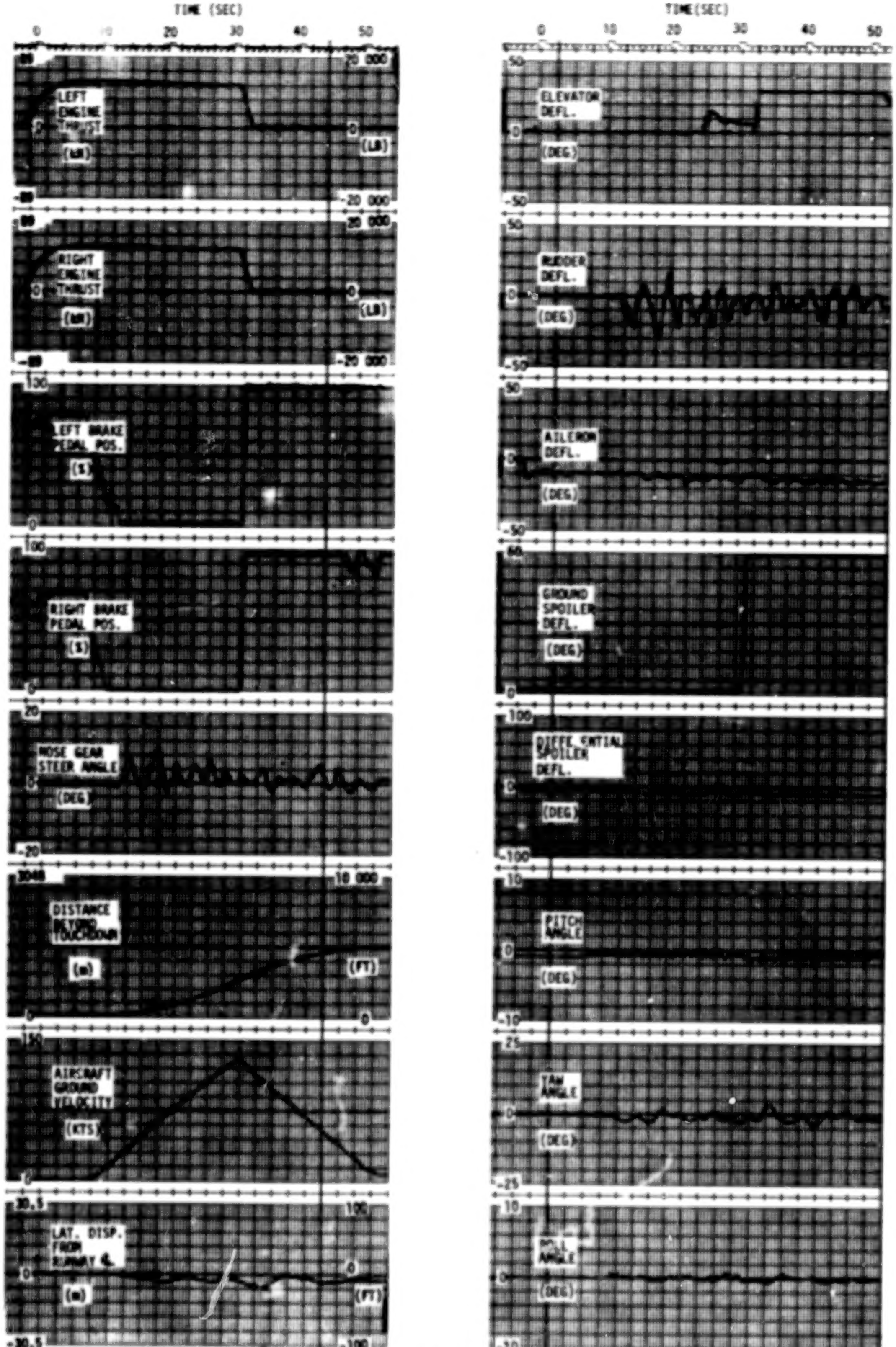


FIGURE 6-9 TYPICAL DRY RTO, BRAKES ONLY, ANALOG ANTISKID, PILOT - WIEBRACHT, RUN-L7

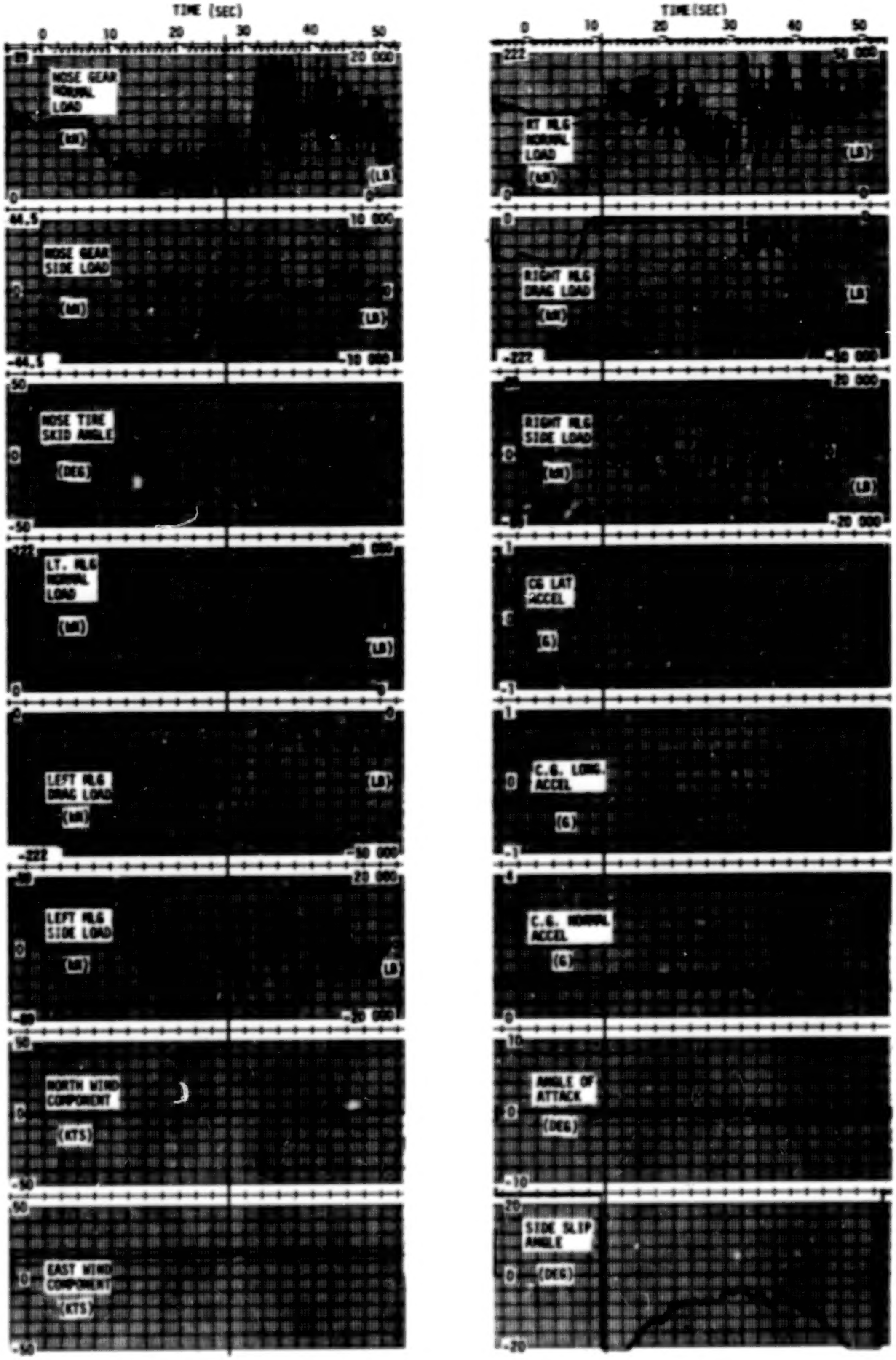


FIGURE 6-9 CONTINUED

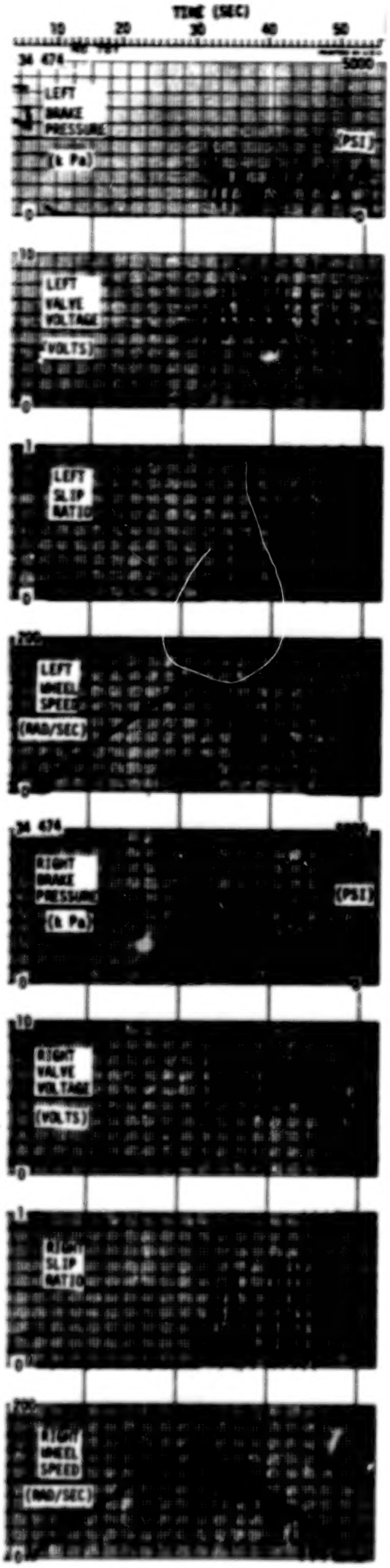


FIGURE 6-9 CONCLUDED

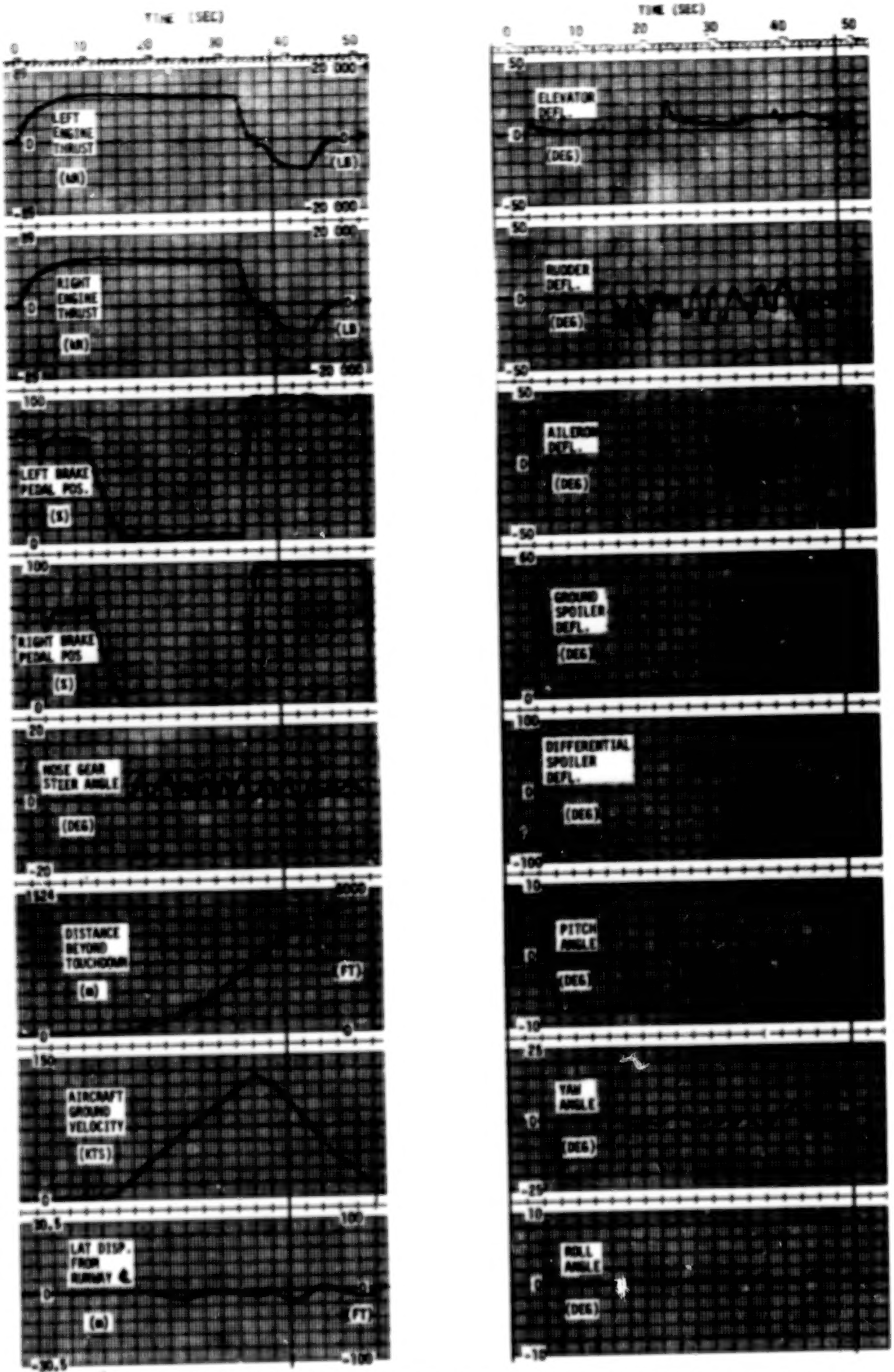


FIGURE 6-10 TYPICAL WET RTO, BRAKES AND REVERSERS, DIGITAL ANTISKID, PILOT - WIEBRACHT, RUN-L17

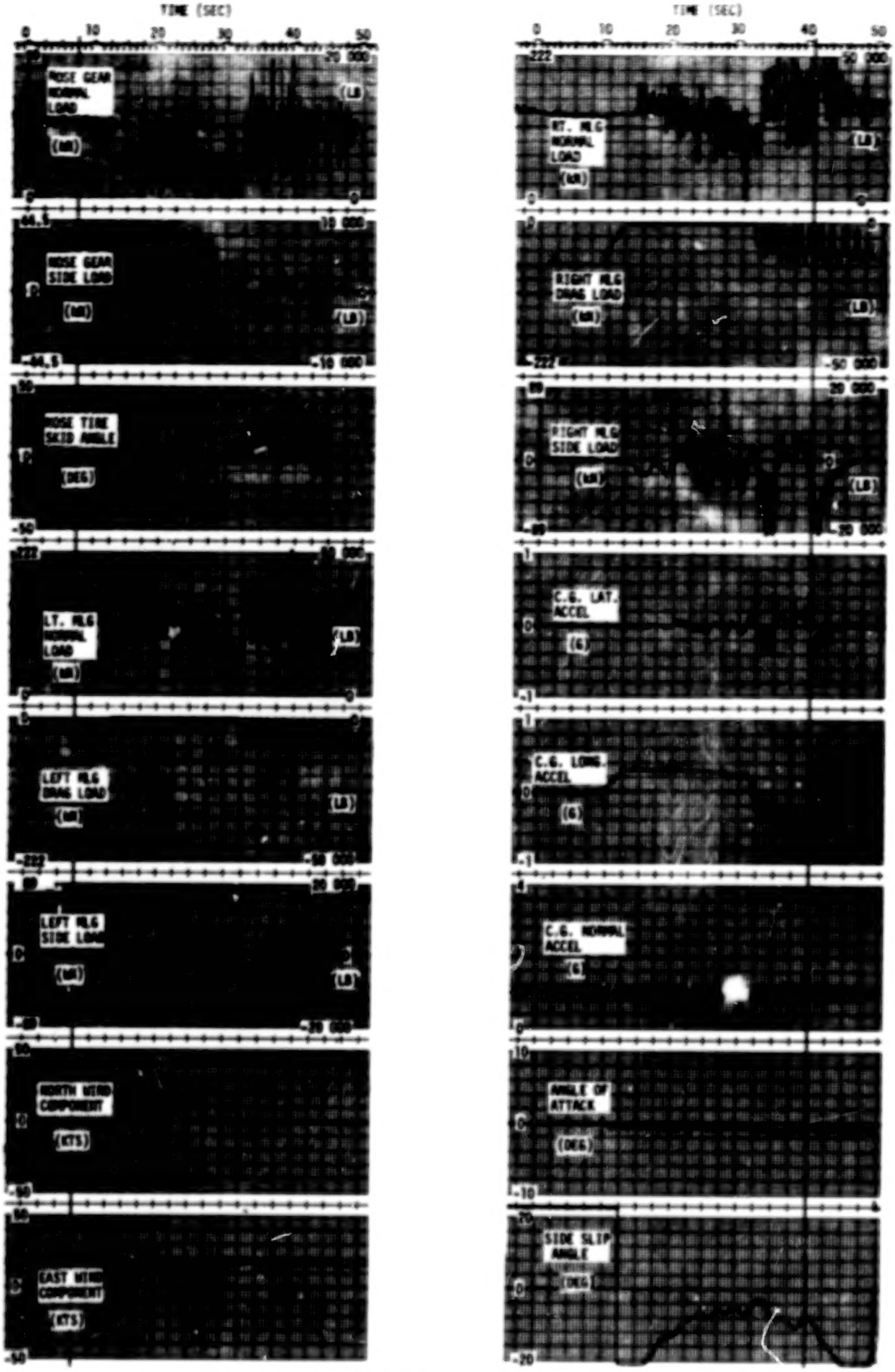


FIGURE 6-10 CONCLUDED

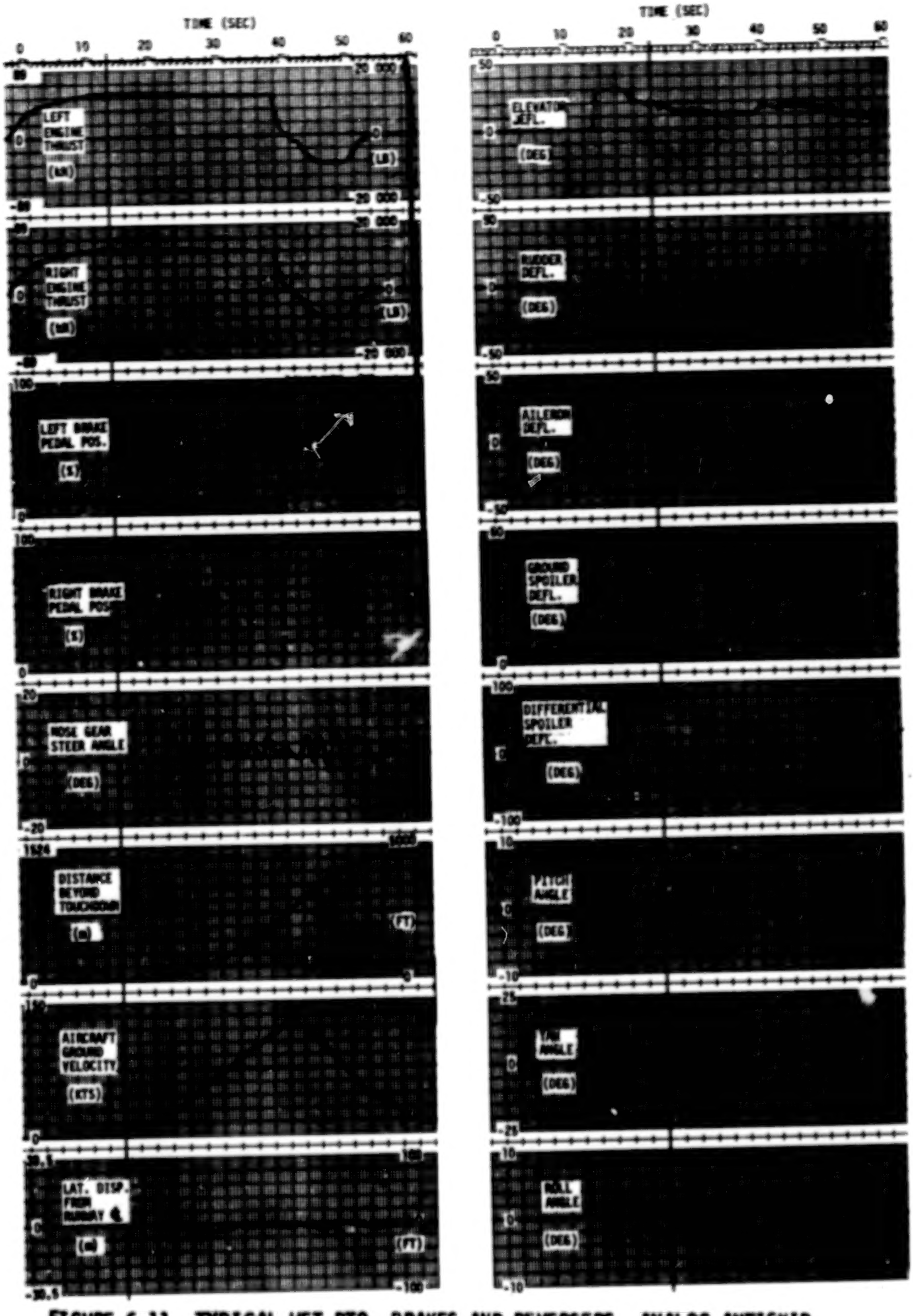


FIGURE 6-11 TYPICAL WET RTO, BRAKES AND REVERSERS, ANALOG ANTISKID, PILOT - WIEBRACHT, Run-L18

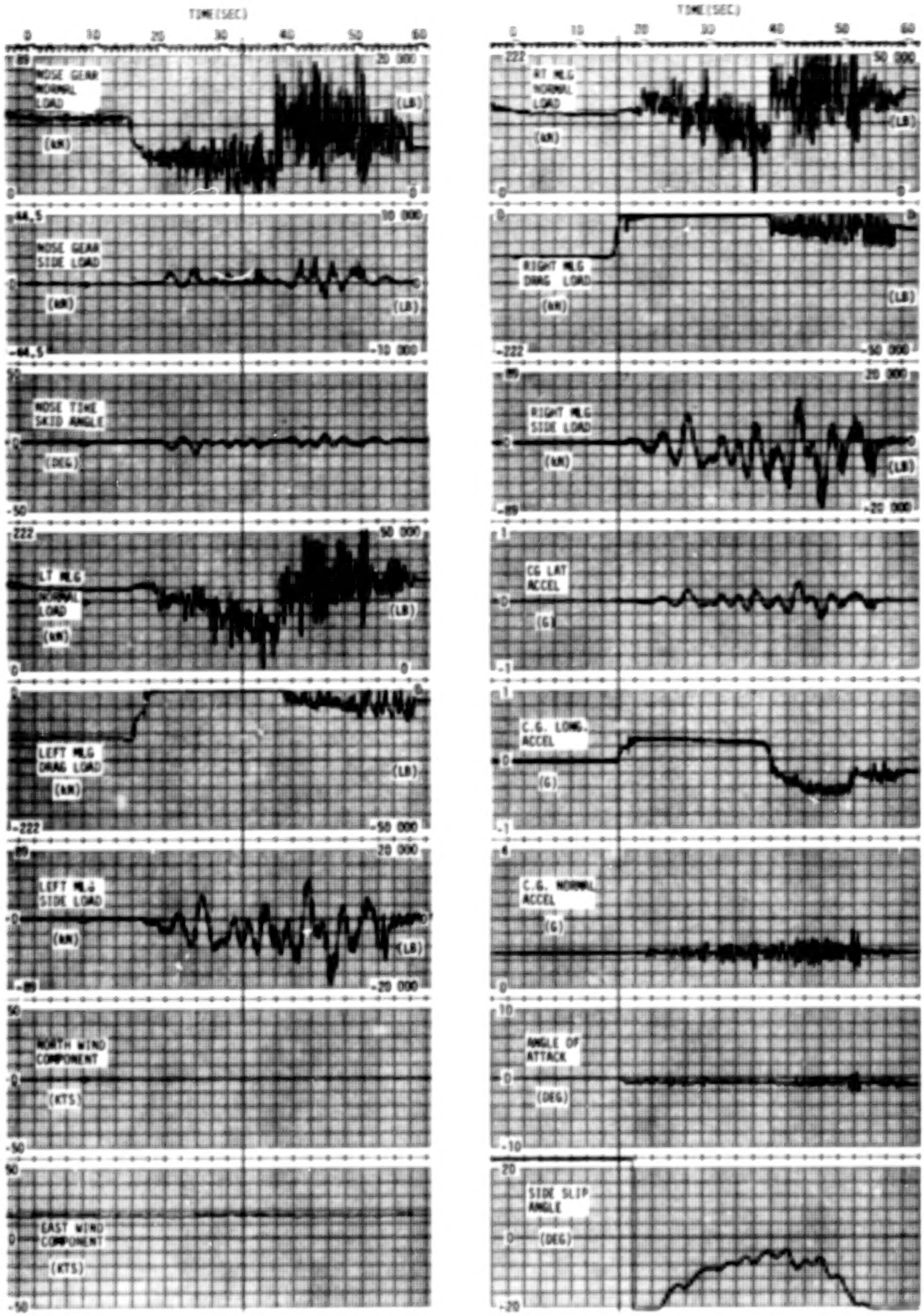


FIGURE 6-11 CONTINUED

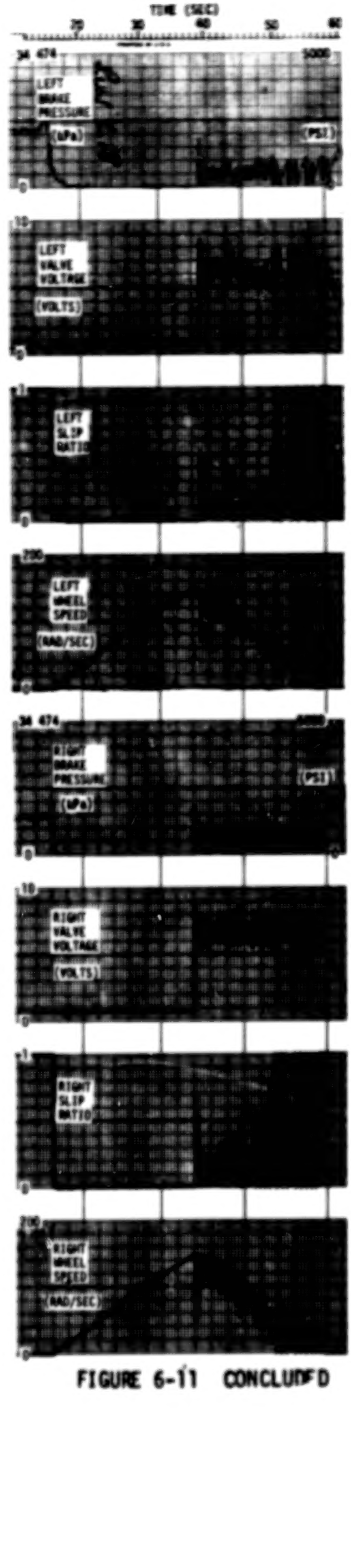


FIGURE 6-11 CONCLUDED

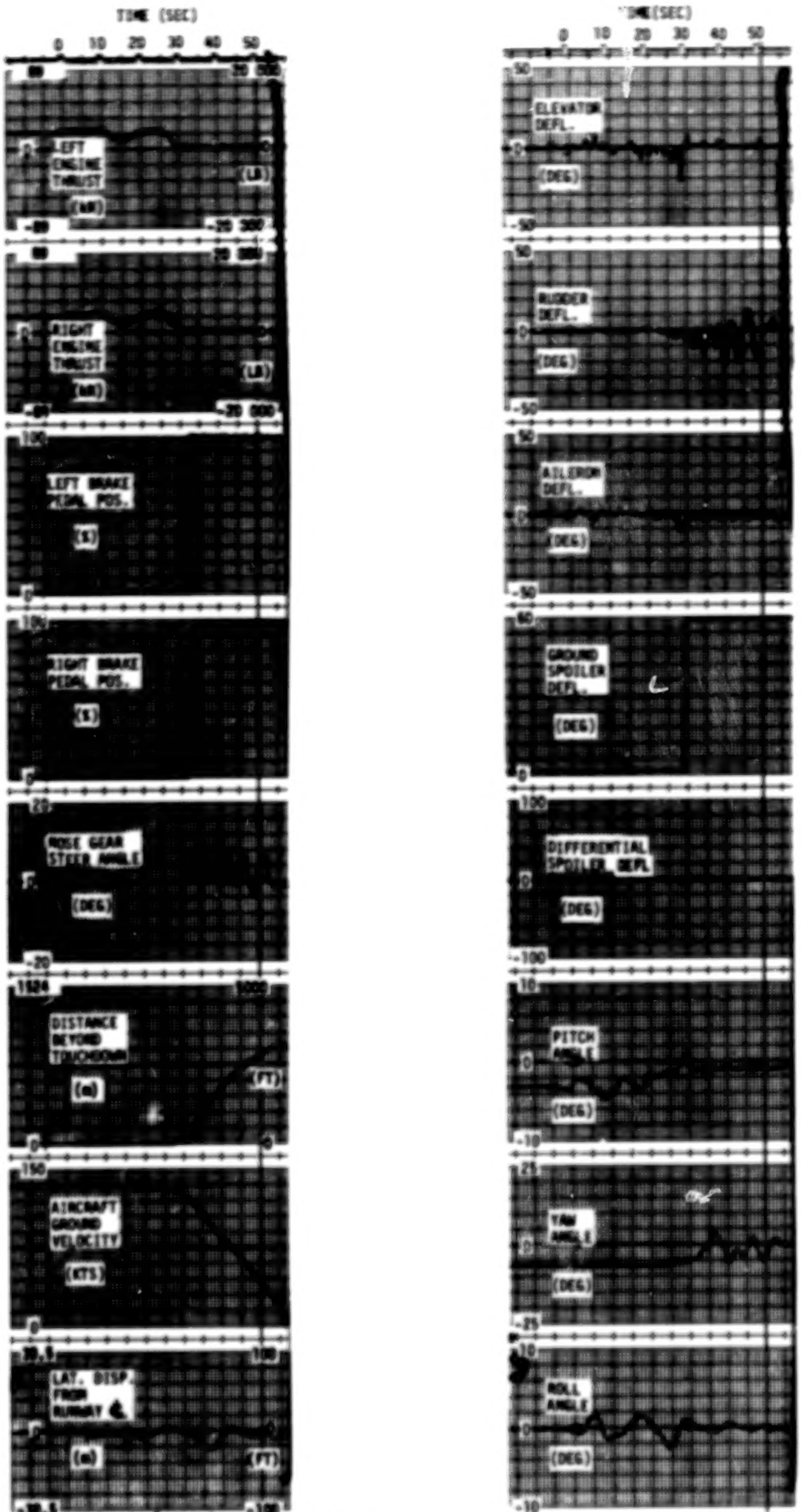


FIGURE 6-12 TYPICAL PATCHY UNSYMMETRIC LANDING, BRAKES ONLY, DIGITAL ANTISKID, PILOT - WIEBRACHT, RUN-118

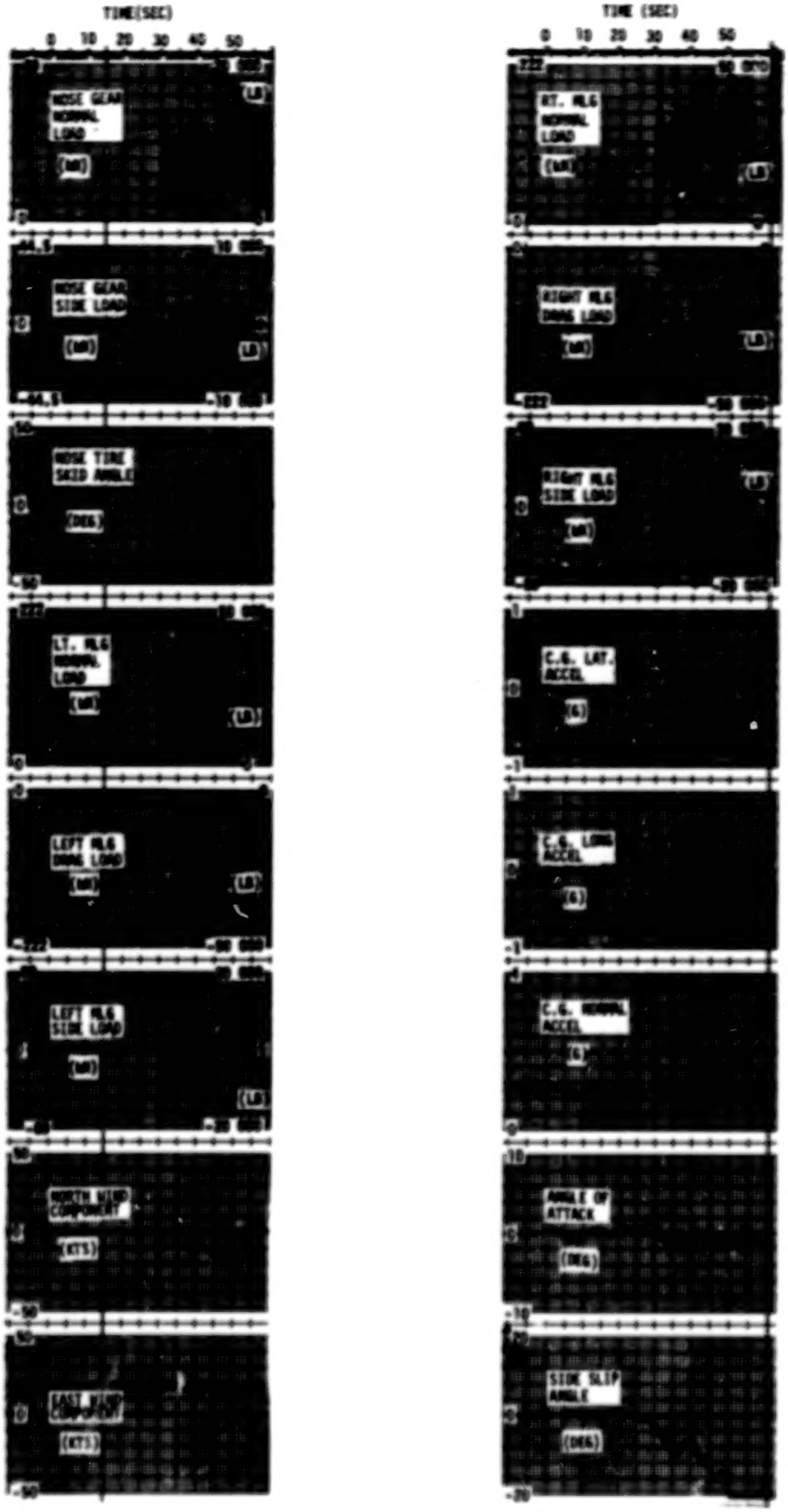


FIGURE 6-12 CONCLUDED

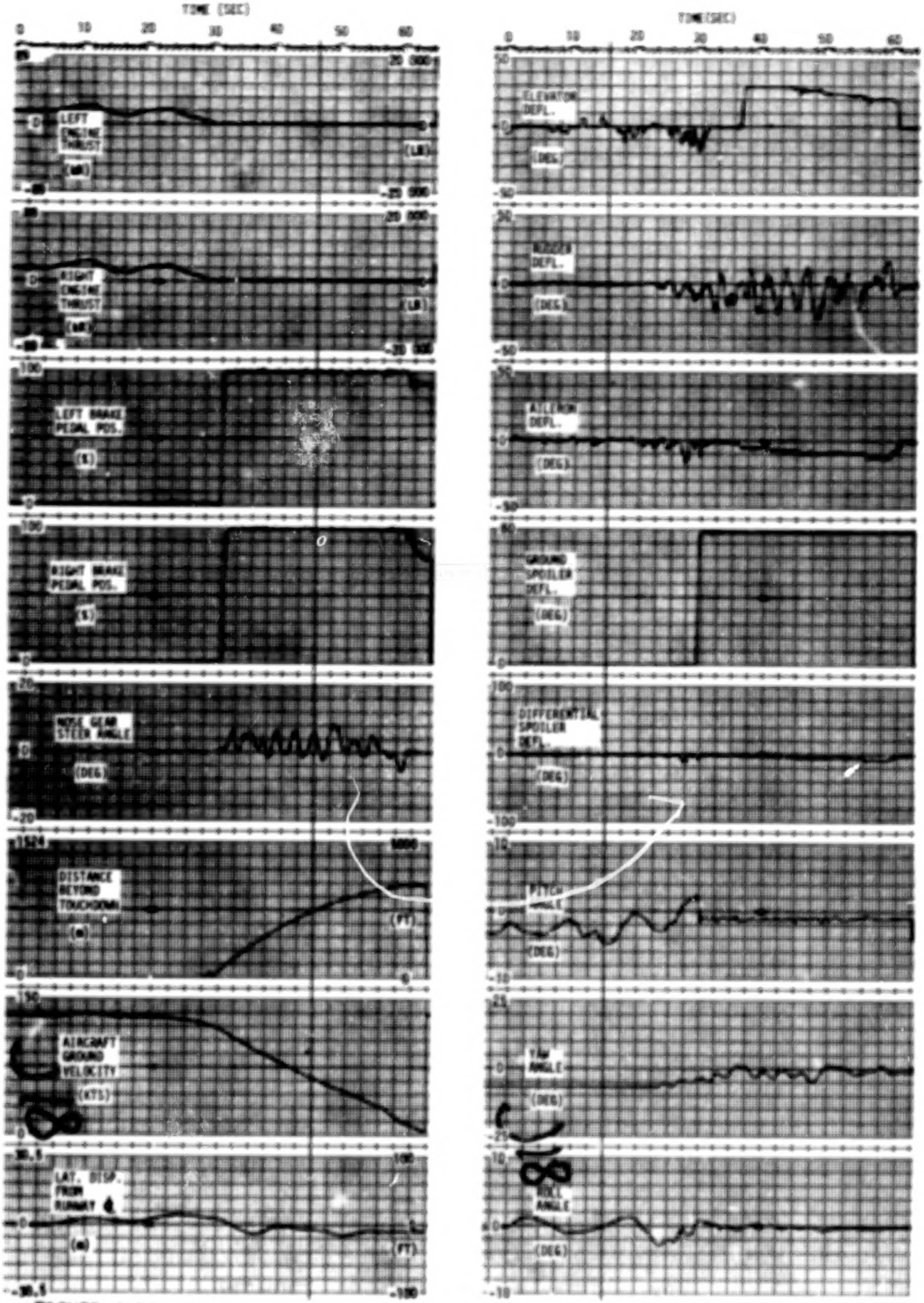


FIGURE 6-13 TYPICAL PATCHY UNSYMMETRIC LANDING, BRAKES ONLY, ANALOG ANTISKID, PILOT - WIEBRACHT, RUN-J18

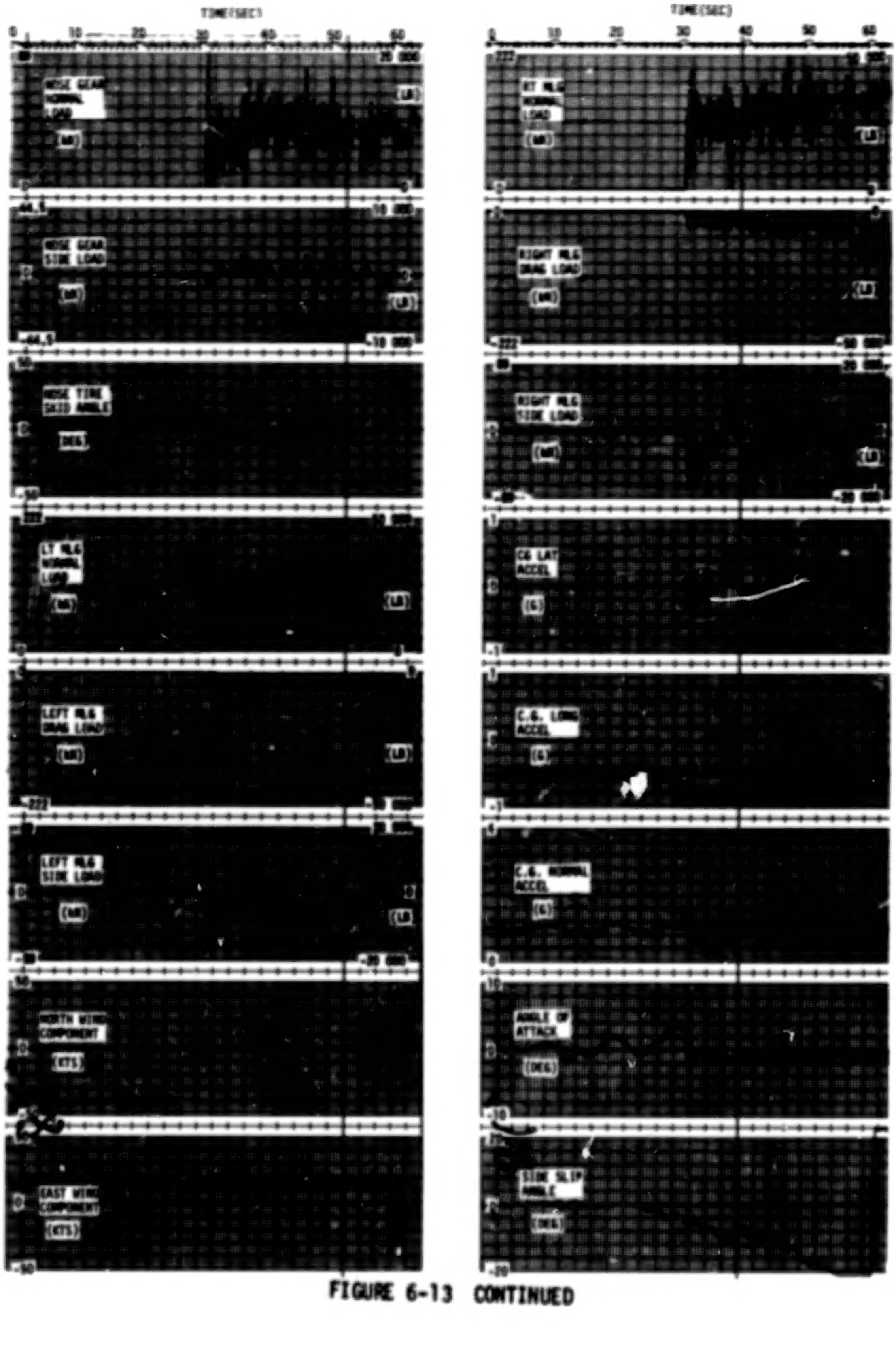


FIGURE 6-13 CONTINUED

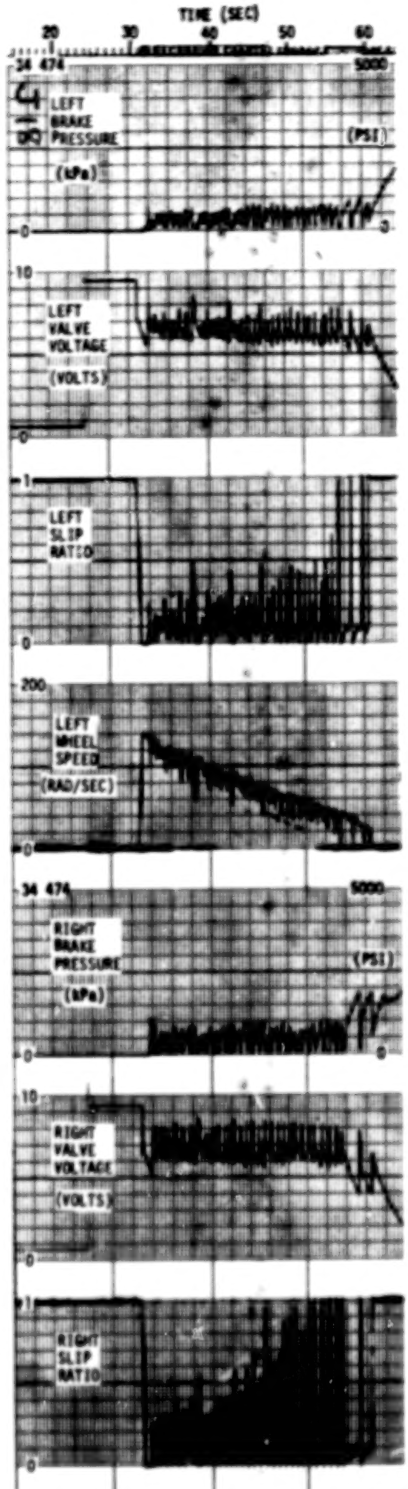


FIGURE 6-13 CONCLUDED

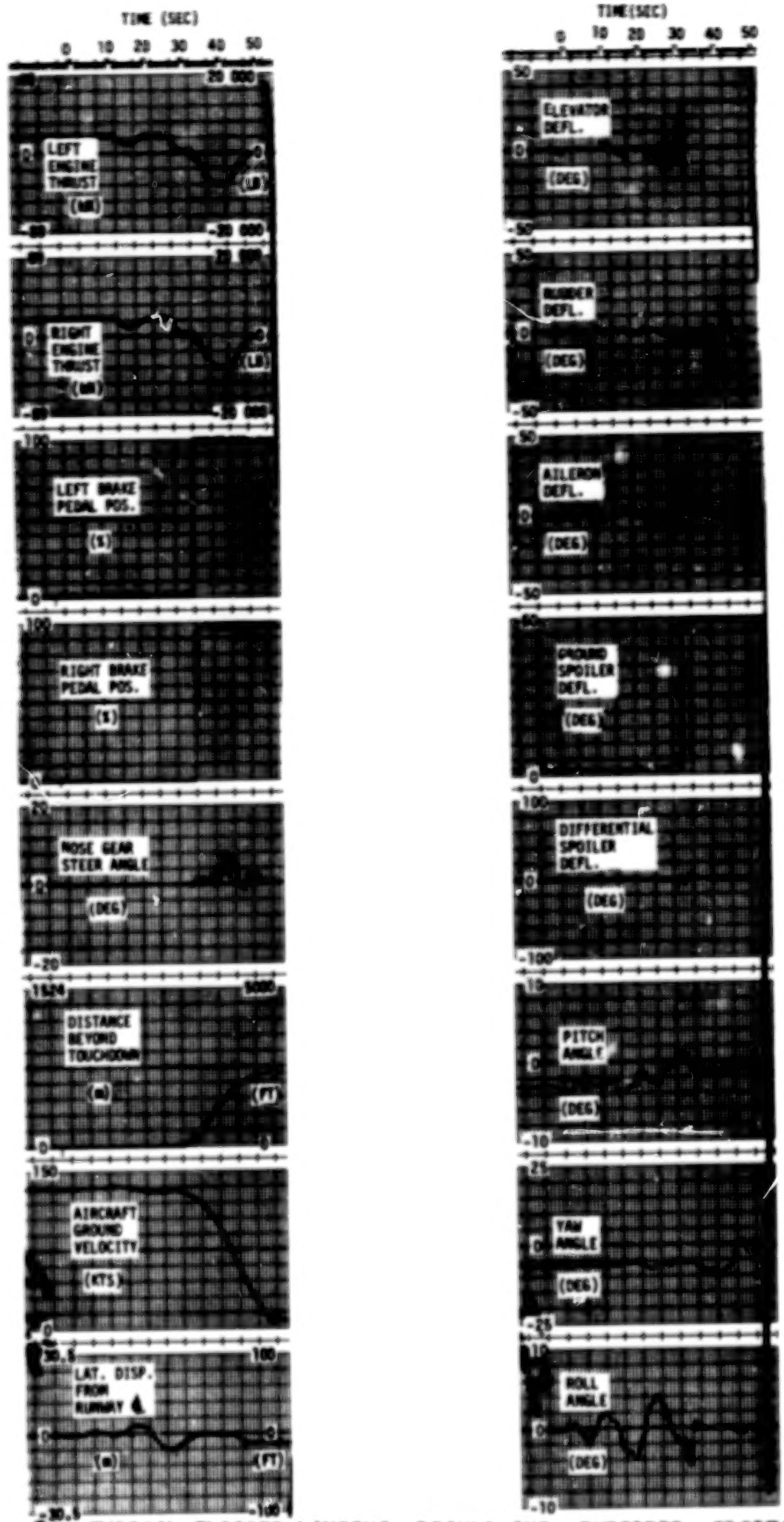


FIGURE 6-14 TYPICAL FLOODED LANDING, BRAKES AND REVERSERS, DIGITAL ANTISKID, PILOT - WIEBRACHT, RUN-122

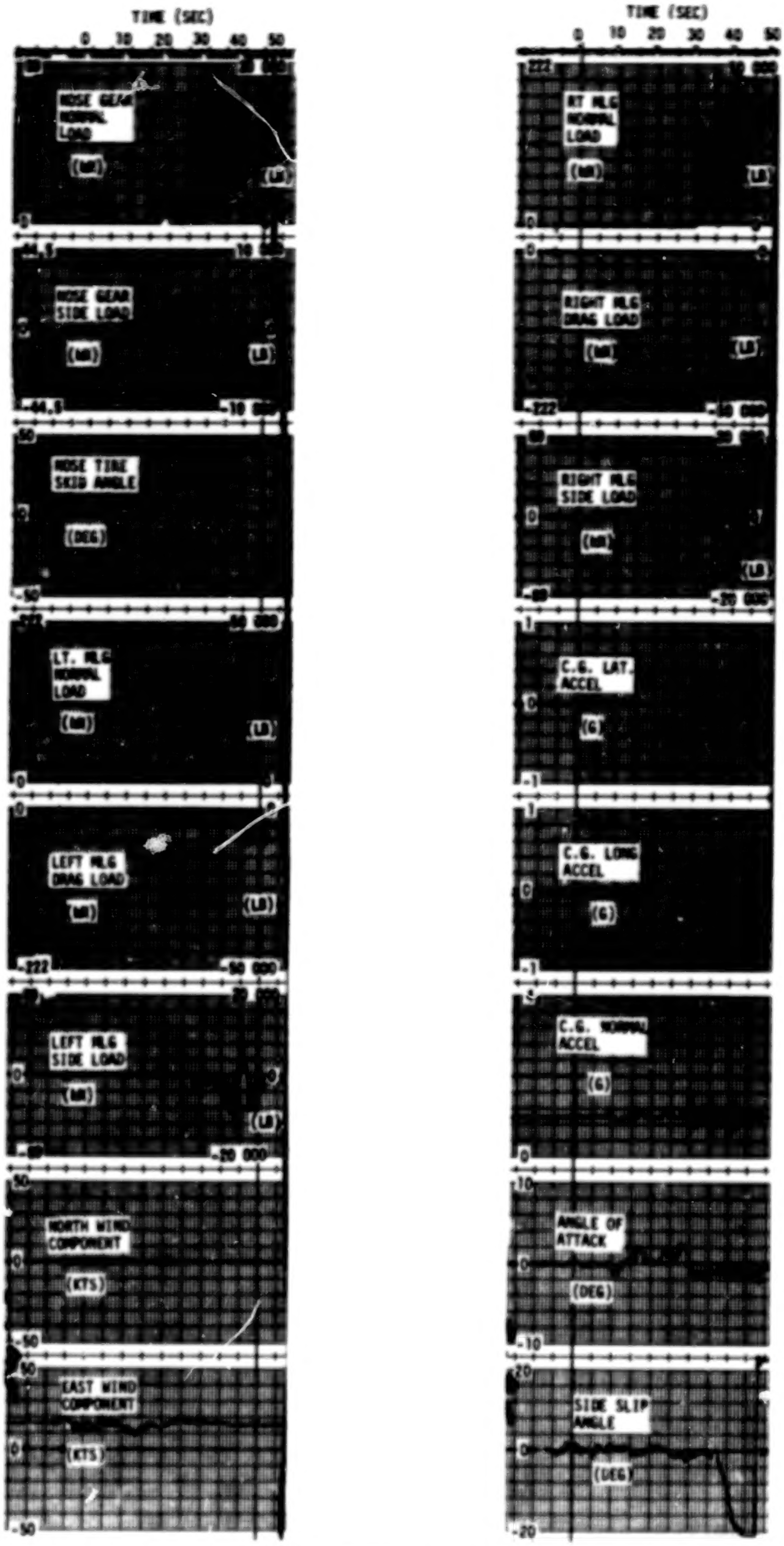


FIGURE 6-14 CONCLUDED

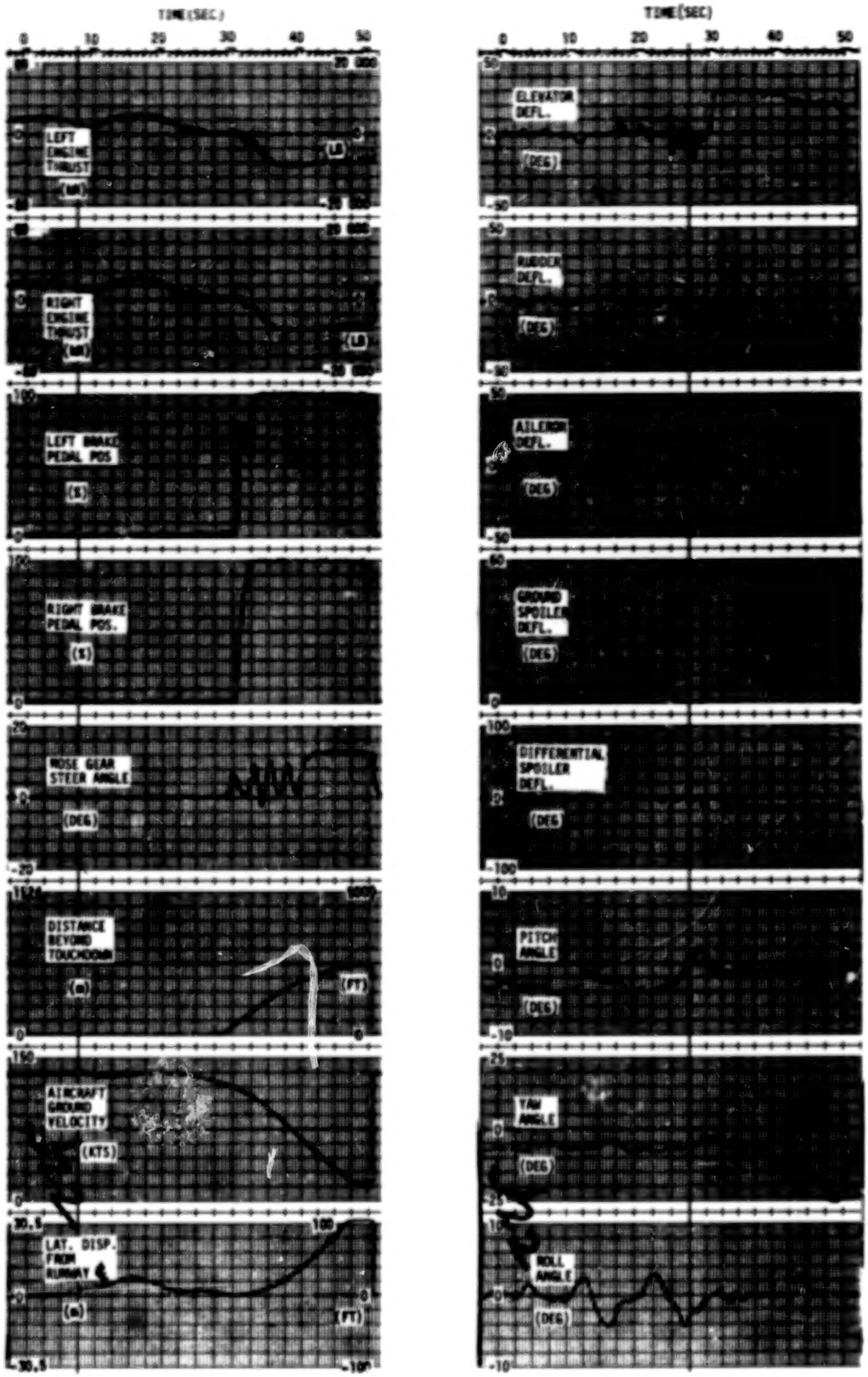


FIGURE 6-15 TYPICAL FLOODED LANDING, BRAKES AND REVERSERS, ANALOG ANTISKID, PILOT - WIEBRACHT, RUN-J22

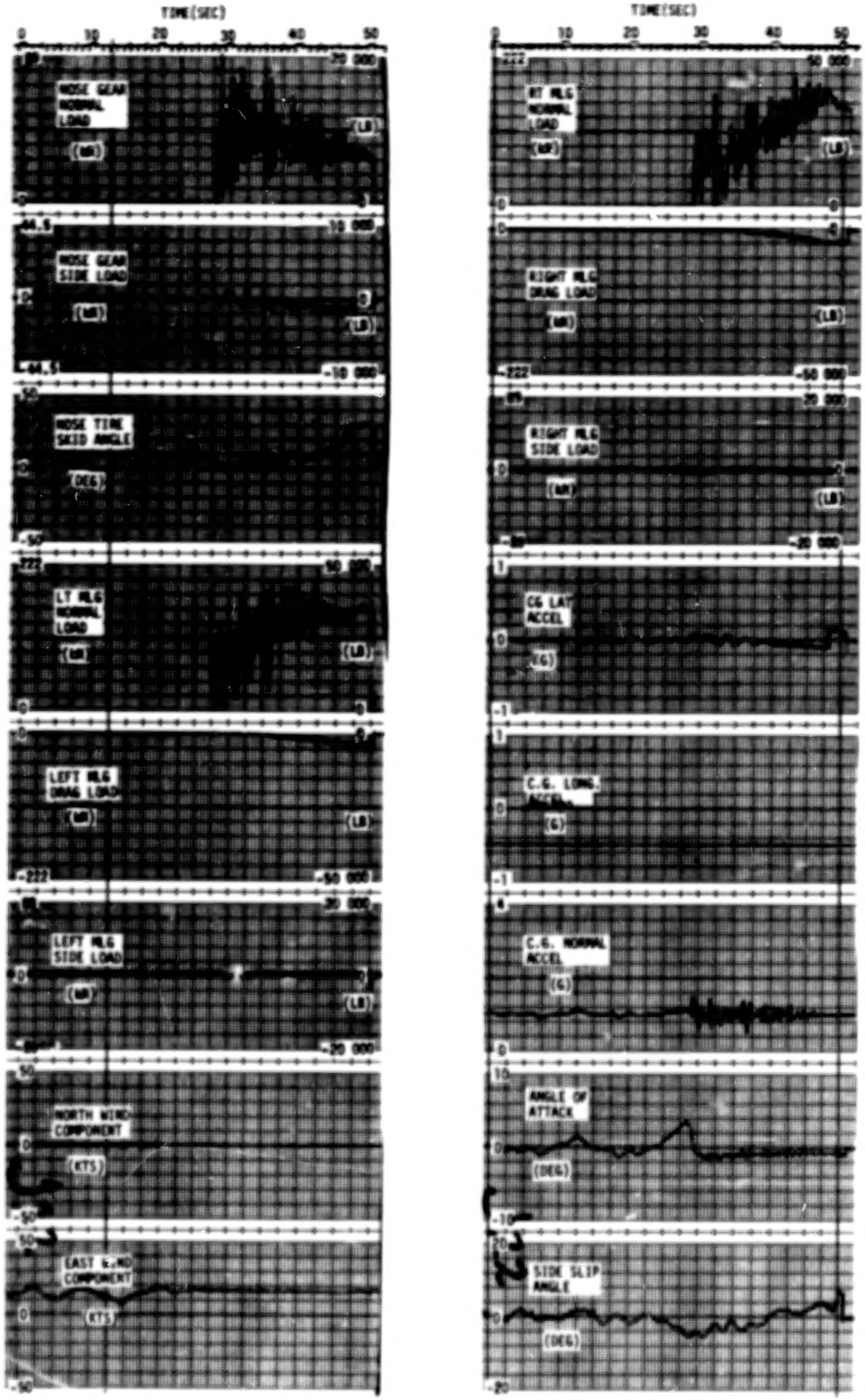


FIGURE 6-15 CONTINUED

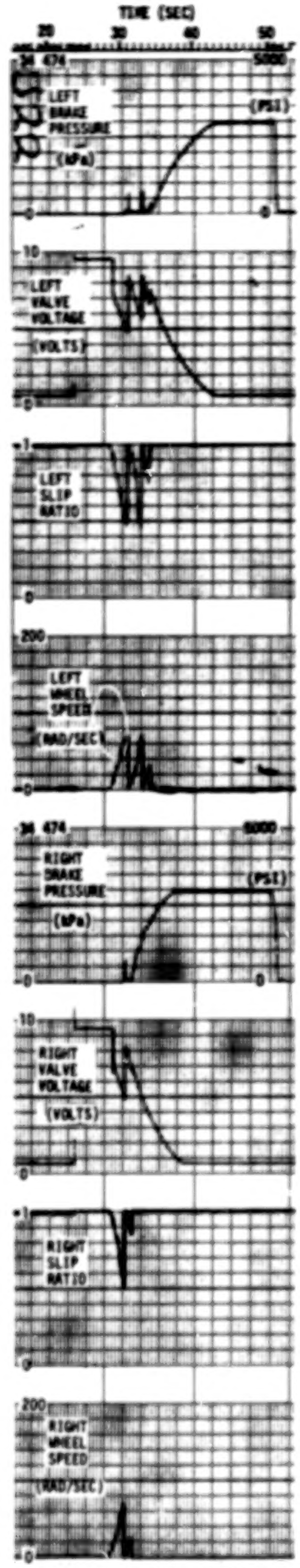


FIGURE 6-15 CONCLUDED

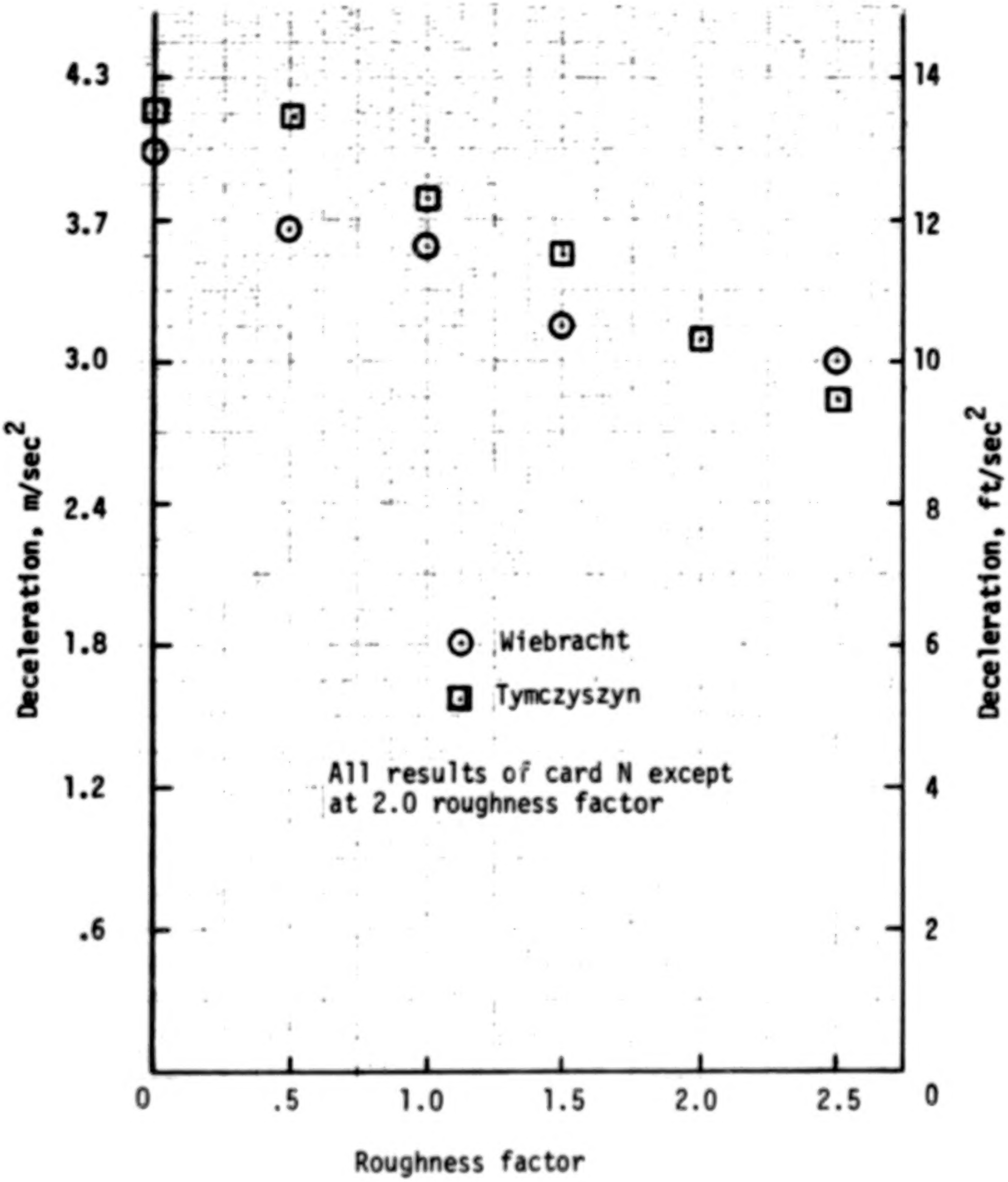


FIGURE 6-16 DISTANCE BASED DECELERATION VERSUS ROUGHNESS FACTOR, ANALOG ANTISKID

TABLE 6-7

PILOT TECHNIQUE FOR FLOODED RUNWAY

15KT CROSSWIND

PILOT

C - WIEBRACHT
D - TYMCZYSZYM

		PILOT PROCEDURE					
		MAXIMUM BRAKING		NORMAL BRAKING		NORMAL BRAKING AND THRUST REVERSE	
	PARAMETER \ PILOT	C	D	C	D	C	D
DIGITAL ANTISKID	MAXIMUM CENTER LINE DEVIATION M (FT)	6.1 (20)	21.3 (70)	3.7 (12)	14.0 (46)	6.1 (20)	4.3 (14)
	MAXIMUM HEADING DEVIATION (DEG)	8	7-1/2	6	3	6	-
	AVERAGE DECELERATION M/SEC^2 (FT/SEC^2)	1.65 (5.41)	1.76 (5.79)	1.69 (5.53)	1.71 (5.61)	3.16 (10.38)	2.98 (9.77)
ANALOG ANTISKID	MAXIMUM CENTER LINE DEVIATION M (FT)	25.6 (84)	7.9 (26)	2.4 (8)	13.1 (43)	2.4 (8)	8.5 (28)
	MAXIMUM HEADING DEVIATION (DEG)	25	9	7	3	9-1/2	12
	AVERAGE DECELERATION M/SEC^2 (FT/SEC^2)	1.12 (3.67	1.23 (4.02)	4.77 (3.89	1.23 (4.04)	2.38 (7.80)	2.13 (6.99)

TABLE 6-8

SUMMARY OF PILOT OPINION OF SIMULATION APPLICATION

PILOT

C - WIEBRACHT
D - TYMCZYSZYN
FAA - FAA COMPOSITE
H - WEINERT
I - ALTREE
K - PASSINGHAM

	APPLICATION	ACCEPTABLE AS IS	NEEDS MINOR REVISION	NEEDS MAJOR REVISION
1	OPTIMIZING PILOT TECHNIQUE ON ADVERSE RUNWAYS		C,D,FAA,H,I,K	FAA
2	TRAINING PILOTS FOR ADVERSE RUNWAY CONDITIONS	D	C,FAA,H,I,K	
3	INCORPORATION INTO 100% SIMULATOR TRAINING SIMULATIONS		C,D,FAA,H,I	FAA
4	ACCIDENT INVESTIGATIONS		C,FAA,H,I,K	D, FAA
5	CONFIGURATION TRADE STUDIES IN AIRCRAFT DESIGN PHASE		D,H,I	C, FAA
6	ESTABLISHING SAFE OPERATIONAL LIMITS FOR EXISTING AIRCRAFT		D,FAA,H,I,K	C, FAA
7	DEFINING REGULATORY REQUIREMENTS FOR AIRCRAFT AND RUNWAY DESIGN		FAA,H,I	C, FAA

TABLE 6-9

POST DEMONSTRATION PILOT QUALITATIVE RATING

RUN \ PILOT		CONTROL DURING APPROACH							
		F	G	H	I	J	K	L	M
P1				5	1.5				3.5
P2	K5	5	5	3	2		2	6	3.5
P3	K2	6	5	3	2		2	6	3.5
P4	K3	6	5	3	2		2	6	3.5
P5				3	2		2	6	3.5
P6				3	2		2	4.5	3.5
P7	K8	6	5	3	2		2	4.5	3.5
P8				3	2		2	4.5	3.5
P9				3	2		2	4.5	3
P10	K10	6	5	3	2		2	4.5	3
P11				4	2		2	4.5	3
P12				4	2		2	4.5	3
P13	K12	6	5	4	2		2	4.5	3
P14	K11	6	5	4	2		2	4.5	3
P15	K9	6	5	4	2		2	4.5	3
P16				4	2		2	4.5	3
P17				4	2		3	4.5	3
P18				2	2		3	4.5	3
P19									
P20									
P21									
P22									
P23									
		5.9	5.0	3.4	2.0		2.1	4.9	3.2
		3.8							

RUN \ PILOT		GROUND DIRECTIONAL CONTROL							
		F	G	H	I	J	K	L	M
P1				5	1.5				
P2	K5	5	3	3	2		3		3.5
P3	K2	6	4	3	2		3		3.5
P4	K3	6	4	4	2		3		3.5
P5				4	2		3		3.5
P6				4	2		3	3	3.5
P7	K8	6	4.5	4	3		3	3	3.5
P8				4	2		3	3	3.5
P9				4	2		3	3	3.5
P10	K10			4	2		3	3	3.5
P11		6	4.5	4	2		3	3	3.5
P12				3	3		3	3	3.5
P13	K12	6	4.5	3	2		3	3	3
P14	K11	6	4.5	3	2		3	3	3
P15	K9	6	4.5	3	2		3	3	3
P16				3	2		3	3	3
P17				3	3		3	3	3
P18				2.5	2		3	3	3
P19				4	3		3	3	3.5
P20				3	3		3	3	3.5
P21				3	3		3	3	3.5
P22				3	3		3	3	3
P23				3	3				
		5.9	4.2	3.5	2.3		3.0	3.0	3.2
		3.6							

RUN \ PILOT		BRAKING DECELERATION							
		F	G	H	I	J	K	L	M
P1				5	1.5				
P2	K5	5	3	3	2		3		3.5
P3	K2	5	3	3	2		3		3
P4	K3	5	3	3	2		3		4
P5				3	2		3		4
P6				3	2		3	1	4
P7	K8	5	3	3	2		3	1	4
P8				3	2		3	1	3
P9				3	2		3	1	3
P10	K10			3	2		3	2	3
P11		5	3	3	2		3	2	3
P12				3	2		3	2	3
P13	K12	5	3	3	2		3	2	3
P14	K11	5	3	3	2		3	2	3
P15	K9	5	3	3	2		3	2	3
P16				3	2		3	2	3
P17				3	2		3	2	3
P18				2.5	2		3	2	3
P19				4	2		3	2	3
P20				3	2		3	2	3
P21				3	2		3	2	3
P22				3	2		3	2	3
P23				3	2				
		5.0	3.0	3.1	2.0		3.0	1.8	3.2
		3.0							

RUN \ PILOT		VISUAL							
		F	G	H	I	J	K	L	M
P1				5	1.5				
P2	K5		3	5	2		5	2	3
P3	K2		5	5	2	5.5	5	2	3
P4	K3		5	3.5	2	5.5	5	2	3
P5				3.5	2	5.5	5	2	3
P6				3.5	2	5.5	5	4	3
P7	K8		7	3.5	2	5.5	5	4	3
P8				3.5	2	5.5	5	4	3
P9				3.5	2	5.5	5	4	3
P10	K10			3.5	2	5.5	5	4	3
P11			4	3.5	2	5.5	5	4	3
P12				4	2	5.5	5	4	3
P13	K12		4	4	2	5.5	5	4	3
P14	K11		4	4	2	5.5	5	3	3
P15	K9		4	4	2	5.5	5	3	3
P16				4	2	5.5	5	3	3
P17				2.5	2	5.5	5	3	3
P18				2.5	2	5.5	5	3	3
P19				2	2	5.5	5	3	3
P20				2	2	5.5	5	3	3
P21				2	2	5.5	5	3	3
P22				2	2	5.5	5	3	3
P23				2	2				
			4.0	3.4	2.0	5.5	5.0	3.2	3.0
		3.7							

RUN \ PILOT		MOTION							
		F	G	H	I	J	K	L	M
P1									
P2	K5		4	3	2	4	4	2.5	2
P3	K2		2	3	2	4	4	2.5	2
P4	K3		2	3	2	4	4	2.5	2
P5				3	2	4	4	2.5	2
P6				3	2	4	5	2.5	2
P7	K8		4	3	2	4	5	2.5	2
P8				3	2	4	5	2.5	2
P9				3	2	4	5	2.5	2
P10	K10			3	2	4	5	2.5	2
P11			4	3	2	4	5	2.5	2
P12				3	2	4	5	2.5	2
P13	K12		4	3	2	4	5	2.5	2
P14	K11		4	3	2	4	5	2.5	2
P15	K9		4	3	2	4	5	2.5	2
P16				3	2	4	5	2.5	2
P17				2	2	4	5	2.5	2
P18				2	2	4	5	2.5	2
P19				2	2	4	5	2.5	2
P20				2	2	4	5	2.5	2
P21				2	2	4	5	2.5	2
P22				2	2	4	5	2.5	2
P23					2				
			3.5	2.7	2.0	4.0	4.8	2.5	2.0
		3.1							

TABLE 6-10

POST DEMONSTRATION PILOT QUALITATIVE RATING

OPERATIONAL PILOT RATINGS COMPARED TO NON-OPERATIONAL RATINGS

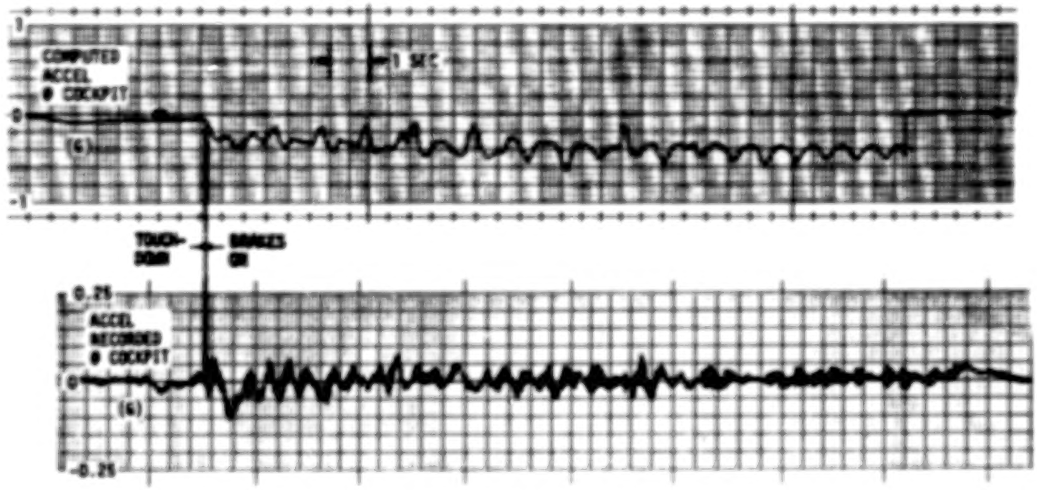
OPERATIONAL PILOTS
- H - WEINERT
- I - ALTREE
- K - PASSINGHAM

NON-OPERATIONAL PILOTS
- F - SOUTHERLAND
- G - ARMSTRONG
- L - ERDMAN
- M - BUGBEE

	CONTROL DURING APPROACH	GROUND DIRECTIONAL CONTROL	BRAKING DECELERATION	VISUAL	MOTION
OPERATIONAL PILOT	2.5	2.9	2.7	3.5	3.2
NON-OPERATIONAL PILOT	4.7	4.1	3.2	3.4	2.7

A) A/C test data at Edwards AFB, Flt. 63 (Ref. 6)

B) Landing, digital antiskid



C) Landing, analog antiskid

FIGURE 6-17 AIRCRAFT, COMPUTED, AND COCKPIT ACCELERATIONS

7.0 CONCLUDING REMARKS

7.1 MOTION BASE SIMULATOR

All pilots who flew both with and without motion commented that runs without motion were degraded. One pilot commented that lack of motion during the flight portion was less disconcerting than lack of motion on the ground. These comments support the conclusion that motion is required for a realistic runway directional control simulation.

Some pilots noted a deficiency of lateral and longitudinal cues. There is a known low gain in the simulator in the lateral direction which may partially explain the lateral motion. However, this condition does not exist in the longitudinal direction. Two studies are recommended to determine the cause: (1) Conduct an end-to-end frequency response between the inputs to the motion drive system and the cockpit accelerations, (2) Review the motion drive equations to determine if they compromise the motion when the plane is on the ground.

7.2 VISUAL SYSTEM

Many pilots commented about the illusion of skidding sideways that the visual system presented. There are several possible explanations for this. One is that the lateral visual cues are good and the longitudinal visual cues are poor. During the V_{MCG} tests the pilot's estimate of his lateral deviation was very close to the actual value. But when a pilot was asked to estimate his speed on the runway from visual cues only, he wasn't accurate due to lack of peripheral cues. The strong lateral cue combined with a weak longitudinal cue may give the illusion of skidding sideways.

A second possible explanation could be the result of a deficient lateral motion cue. If the acceleration cues don't accompany the visual cue, the illusion of skidding sideways may be apparent.

Some pilots commented about the fuzziness of the visual scene. This could be a fixed focus phenomenon.

Several pilots commented about difficulty with depth perception. This could be related to the lack of peripheral cues. One pilot commented that this cue is difficult even in reality. Some pilots did notice a time lag in the visual scene.

7.3 AIRCRAFT SIMULATION

The comment that the ground directional control was too sensitive was made a number of times. A good qualitative validation is needed to investigate this. However, no flight test data exists for comparison.

Another comment made several times was that a pilot would make an input, observe that the initial response was not enough, add more input, and then the simulation would over respond. Possible reasons could be lags in the visual system or an improper steering simulation.

The addition of sound was suggested several times. The pilots wanted to hear the nose gear thump down and the sound of engines during thrust reverse.

7.4 ENVIRONMENTAL SIMULATION

The runway roughness produced realistic cockpit motions. When runs were made on smooth pavement the result was unrealistic.

The gust and wind response was not as expected for some pilots. The gust model was for light turbulence and there was not time during the program to try other conditions.

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7.5 ANTISKID BRAKE SYSTEM SIMULATION

Many pilots felt that the motion cue from the digital antiskid gave better representation of cockpit feel than the analog system. A possible reason for this may be that the motion gain was so low that only the digital could drive it hard enough. Then if the motion gain would be increased, the digital would be too severe.

More importantly, the digital antiskid was too simplified to give proper results. The main case in point is the flooded condition. On this surface the digital antiskid gave little directional control problems while the pilot had his hands full with the analog. The reason is that the digital antiskid system does not reflect hydroplanning conditions as does the analog antiskid system.

7.6 USES OF THE SIMULATOR

The pilots' opinion of the uses for the simulator are tabulated in Table 6-8. The use of the simulator for adverse runway training rated the highest. Some pilots commented after runs on flooded runways that it was a very good training experience. Use of the simulator for other purposes requires acquisition, incorporation, and validation of directional control flight test data. Also sound would help.

7.7 GENERAL

In the preparation of this report, emphasis has been placed on highlighting the constructive critical comments made by the pilots. This was done so that future programs could address these criticisms and thus take another step forward in developing simulator capability necessary for aircraft ground handling on runways. To allay any possible negative impression that this technique can produce, the following comments relative to the simulation are included:

Dave Wiebracht - "The overall feeling is that this program is a great step forward in simulation in an area which has been almost totally lacking in past simulators. The flare, touchdown and rollout simulation (or lack of) is the greatest constraint to total training in a simulator. But more than that, a new dimension of training is possible to enable inexperienced pilots to become familiar with hydroplanning and reverser characteristics on wet runways with crosswinds. A most needed area of training today."

George Jansen - "Felt pretty good all the way around. Toward the end of the run, I put in right rudder to get a 20 foot deviation then left rudder and it came back well. Digital antiskid was good - about as representative as it ever will be."

Nick Knickerbocker - "Good simulation of going through something wet and then biting into the dry. Overall that was a pretty good run."

George Lyddane - "Good deceleration - a little jerky especially at the slow speeds. Pleased with overall braking. Tracking is good - landed to the left and was able to correct with brakes - antiskid cycling representative."

Joe Tymczyszyn - "Great - I liked that - that run was the most realistic run, that was good - I liked the added deceleration with the reversers. Most realistic runway roughness profile. Program progress excellent. Knees and ankles tired after 23 runs."

Perry Deal - "Whole thing from start to finish very realistic - has everything."

Ernie Southerland - "Good cycling on antiskid. Good model."

Don Armstrong - "Excellent presentation of flooded landing response."

Ron Weinert - "Real feeling of runway - seems overly rough at times. Reality better than anything I have seen. Runway is a tad rough but representative."

Jack Altree - "This simulator has good potential for use in all areas mentioned for possible use."

Sal Nucci - "Fantastic training experience."

Alan Passingham - "Directional control is realistic for aircraft. RDC simulation would appear to be a potential asset for training purposes. Our operations frequently experience contaminated runways and so RDC simulation would be very valuable."

Ken Erdman - "I've never experienced this condition before."

Jim Bugbee - "When landing on flooded runway I needed more height and speed calls - psychologically I was in an airplane."

7.8 AUTHOR'S CLOSURE

The objectives of the program have been met. The development and successful evaluation of the simulator represents a substantial step forward in the development of simulator capability necessary to study and solve aircraft ground handling problems on runways.

The simulator in its present configuration can be used to train pilots for adverse runway operations. Some evaluation pilots experienced conditions they had never encountered previously, and now have a better idea of what to expect.

The simulator can also be used for development of less subtle elements of pilot technique as was demonstrated by the flooded runway analog runs.

The simulator can also be used to assess operational procedures such as the 70 kt turn maneuver.

Of course, there are areas where improvements can be made, but the simulator can be used in its present configuration for many meaningful purposes.

8.0 CRITIQUE AND RECOMMENDATIONS

Incorporation of the following suggestions would improve the overall results of a similar program.

Procedure

(a) The number of different cases should be minimized. Numerous different cases tend to confuse the results.

(b) Develop more specific questions for pilots that can be answered yes or no and, if no, why.

(c) Develop a better qualitative rating system. The variation of numerical ratings were too large.

(d) Record all data on magnetic tape. This would allow convenient storage, access, and duplication.

Simulation

(a) The digital antiskid is inadequate in certain areas and needs redevelopment.

(b) More flight test data is required for correlation of directional control performance.

(c) A study of the motion and motion drive system is needed to find the reason that the motion was deficient for operation on the ground.

(d) The reason for the sensation of visual skidding and fuzziness should be found.

(e) Expansion joints need to be added to the model for off-centerline visual cues.

Studies

(a) A study should be made by conducting runs with reduced visibility. This would simulate a typical landing where little peripheral vision is available.

(b) A study to determine the minimum nose gear static load required to maintain directional control would be interesting.

(c) Another interesting study would be the impact that nose gear braking has on aircraft directional control.

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